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Developing A Set of Holistic Signal Retiming Performance Metrics: An Evaluation of Signal Retiming Efforts in Austin

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Developing A Set of Holistic Signal Retiming Performance Metrics: An Evaluation of Signal Retiming Efforts in Austin

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Abstract

Developing A Set of Holistic Signal Retiming Performance Metrics: An Evaluation of Signal Retiming Efforts in Austin

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Evaluating signal retiming efforts is a crucial next step for transportation agencies after retiming their corridors. By analyzing the quality of their retiming efforts with respect to their initial goals for the retiming process, agencies are able to quantitatively assess the effects of signal timing changes and allocate their future resources appropriately. The wide variety of transportation data sources available also facilitates the possibility for agencies to develop a set of performance measures with which to evaluate signal retiming efforts. This thesis presents a set of developed signal retiming performance metrics for use in before-and-after comparison studies that together consider the holistic effect of signal timing changes. These performance metrics are applied to several retimed corridors in the City of Austin to evaluate the effect of signal timing efforts. While more data is needed to supplement several of these performance metrics, these measures significantly improve the current one-dimensional evaluation process used by the City of Austin that relies solely on travel time changes obtained by floating car runs. Finally, this work also includes an initial investigation of seasonal variation on a sample corridor in Austin which could be used to enhance the flexibility of the City of Austin's retiming schedule and strengthen its understanding of travel time data throughout the year.

Keywords: evaluation, performance metrics, traffic signal retiming, corridor performance, data sources, seasonal variation

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PART 1: BACKGROUND AND DEVELOPMENT OF METHODOLOGY

Chapter 1: Introduction and Project Motivation

Signal retiming is touted as one of the simplest and most cost-effective ways to improve travel along a roadway. The benefits of periodic retiming include reduced delays, improved progression along a corridor, reduced emissions and fuel consumption, safety improvements, and overall improved traffic operations on a network (Sunkari, 2004). As agencies invest resources into the extensive process of signal retiming (data collection, analysis, plan generation, optimization, implementation, etc.), it is imperative that a thorough before-and-after evaluation of retiming efforts be conducted to ascertain if performance has indeed improved. By assessing the quality of retiming efforts, agencies can reap the full benefits of signal retiming by determining if and to what degree their objectives were met through the modification of signal timing parameters. With the proliferation of more robust transportation data sources, agencies are becoming increasingly more capable of conducting these evaluations using quantitative metrics that can demonstrate the quality of their signal retiming efforts to the public and to city officials.

The City of Austin (CoA) Transportation Department is responsible for periodically retiming the city's 1,000+ traffic signals to maintain safety and performance along its corridors. Historically, the CoA has used end-to-end corridor travel time obtained by floating car runs as its sole metric for evaluating the effect of retiming efforts. However, city signal engineers are noticing that the observed travel time benefits of signal retiming are becoming smaller and smaller as the room for improvement shrinks on already optimized corridors. While travel time is of great importance to the public, engineers also consider other factors such as reliability, safety and multimodal benefits in their retiming efforts. The city's one-dimensional evaluation process focused solely on one metric is unable to capture the true holistic effect of their corridor retiming efforts that aim to improve all facets of the user experience through a network of signalized intersections.

This thesis presents a step towards developing additional performance metrics using other, more robust, data sets made recently available to the CoA to create a comprehensive evaluation incorporating other non-vehicular modes and considering side-street traffic and cycle length adjustments. This work resulted in the development of six performance metrics from varying data sources that better capture and quantify the holistic effects of the CoA's retiming efforts. The following chapters include a review of the literature surrounding signal retiming performance metrics and potential data sources, the development of each performance metric, and eventually the application of the developed metrics towards evaluating retiming efforts on two corridors in Austin. In addition, this thesis includes a continuation of prior efforts to develop a data-centric methodology for prioritizing corridors for retiming as well as an exploration of the variation in corridor speeds across all times of the year.

Chapter 2: Project Background and Existing Data Sources/Processes

2.1 EXISTING COA SIGNAL RETIMING EVALUATION PROCESS

Currently, the CoA conducts floating car runs along a corridor on a single day before retiming and on a single day after retiming to obtain travel time information for the calculation of a percent travel time reduction value. Usually, the CoA will aim to record travel times for at least three runs of the full corridor length for every direction along the corridor during every time period (typically an AM peak, an Off-Peak and a PM peak period) for both the before and after retiming scenarios. During these runs where total travel time is recorded, the CoA will also record the total number of stops made along each run of the entire corridor.

Afterward, the travel time reduction metric for a single corridor is calculated by summing the average travel time values among equivalent runs for all time periods and directions that occurred before retiming, doing the same for the runs taken after retiming occurred, and calculating a percent difference between the before and after scenarios. The CoA then calculates this information for all retimed corridors in a particular fiscal year to yield a single system-wide travel percent time reduction value. This calculation also makes use of volume estimates along the corridors to weight the calculated percent changes in travel time for each corridor to account for the varying magnitude of users impacted by changes along each corridor. In the same way, the number of stops can be used to calculate a percent difference in the number of stops made along the corridor. CoA staff can then easily present these system-wide metrics to members of the public or to city officials to provide a quantitative assessment of the travel time effects of their retiming efforts that is meaningful and easy to understand. However, since these metrics are based on a small sample of only a few floating car runs performed on a single day for each corridor, there is a risk for random variation affecting the accuracy of these metric values.

2.2 REVIEW OF AVAILABLE DATA SOURCES

The CoA has access to a variety of data sources, including INRIX, Traction, GRIDSMART camera data, and high-resolution data. Each source is unique in its functionality for retiming evaluation purposes and its availability throughout the network.

INRIX roadway analytics data was previously used in earlier work for corridor prioritization and has remained the CoA's strongest data source with regards to network coverage (Dunn, 2018). INRIX provides travel time data using a segment-based system, with individual segments varying in length from 0.005 miles to one mile long. INRIX also cleans its data before providing it for users, which eliminates outlying data that is uncharacteristic of overall travel trends. However, this data cleaning process creates an averaging effect, as discussed in a later section of this report, that mitigates the observed peaks in travel time trends.

In a similar family of data, Traction was a secondary source of travel time data that was used to analyze travel time. Traction is a Kimley-Horn developed software that provides crowd-sourced data from Azure/Tom-Tom, Waze, and Google data sets (Kimley-Horn, n.d.). Unlike INRIX, Traction defines corridors on a point-to-point system, where a user can specify the start and end point of a study corridor without having to include or exclude irrelevant road sections based on arbitrary segment lengths. Along a user-defined path, Traction provides travel time data for only the trips that travelled the path from start to end. This is an advantage of Traction over INRIX data, which includes trips covering only a portion of a defined corridor that could demonstrate travel time variations as they turn onto or off of a corridor. A disadvantage of Traction over INRIX data is that the CoA has a limited monthly credit allowance with Traction that limits the number of corridors on which it can collect data. Historical data is also not available for any date prior to the date which a corridor was defined. This requires CoA staff to carefully plan the corridors for which they choose to collect data each month based on the streets they wish to monitor and/or plan on retiming. This also means that Traction (at its current credit allowance) provides no capability to support the prior prioritization work conducted through this project and/or any seasonal variation studies.

The CoA also has access to GRIDSMART cameras located at intersections around the city. The CoA has upwards of approximately seventy GRIDSMART cameras located around Austin. Figure 1 depicts the data coverage for the GRIDSMART dataset. The cameras are able to track vehicle trajectories as drivers approach, pass through, and exit an intersection by detecting vehicles with digitally specifiable zones that act like induction loops (GRIDSMART, 2019). The GRIDSMART user-interface allows CoA staff to monitor traffic conditions across the city in real-time with 360-degree fisheye lenses and also facilitates the retrieval of passenger vehicle counts, heavy vehicle counts, approach speeds, and a variety of other data at an intersection. Prior experience with GRIDSMART data has indicated that its vehicle speeds can often be untrustworthy and inaccurate. Given that the CoA's retiming evaluation methodology lacked a vehicle volume component, GRIDSMART's functionality for this project was its provision of vehicle volume information at intersection approaches along corridors during the retiming process. For the purposes of this project, only vehicle count data was extracted from this data source to generate a throughput metric.

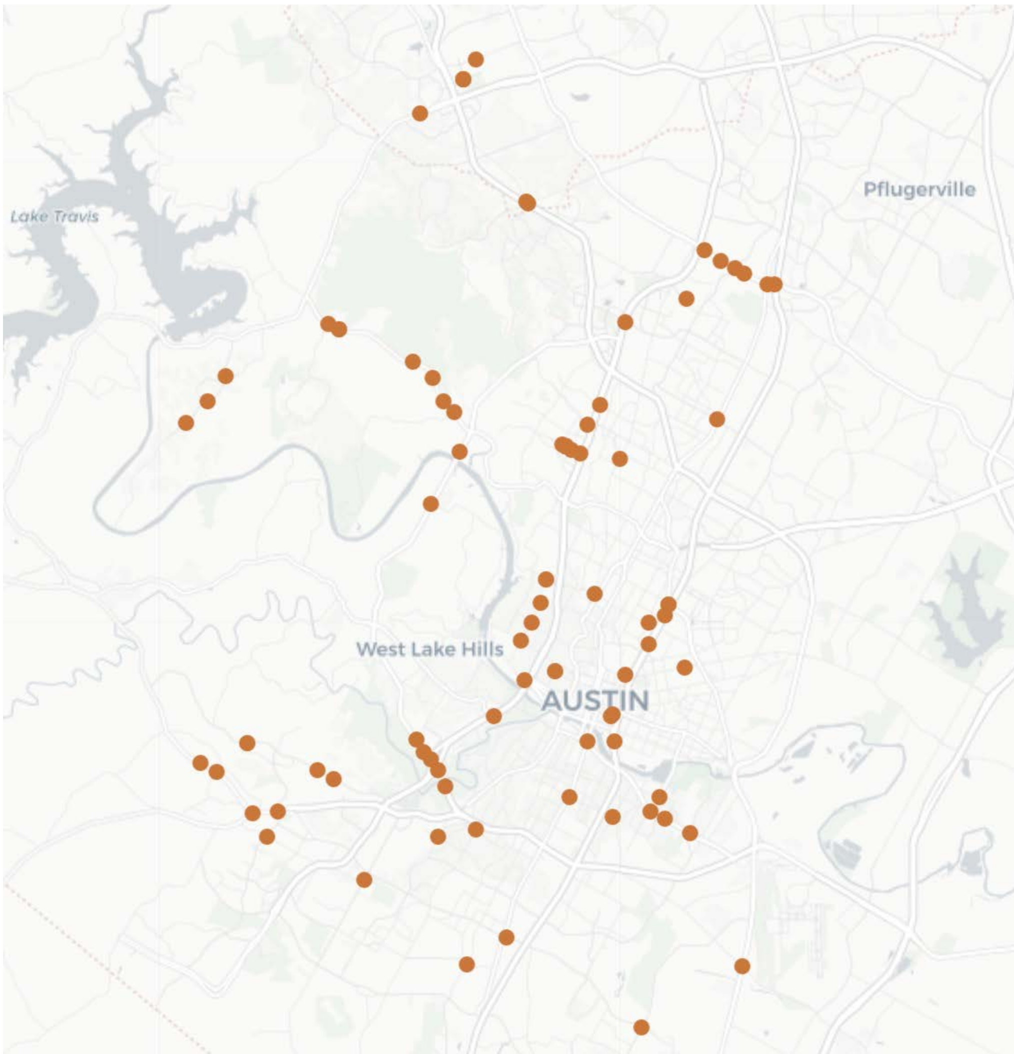

Figure 1: Map of GRIDSMART Camera Data Coverage for the City of Austin

According to CoA staff, it is common for some of their GRIDSMART camera systems to shut down periodically and fail to record data during those times. Another source of unreliability with this data source is that the cameras themselves are also subject to their own errors in detecting vehicles due to changes in external factors such as lighting and weather.

A newer source of data for the CoA is high-resolution data. High-resolution data is the result of a signal controller logging intersection events (such as the start of yellow clearance) every tenth of a second. In order to implement high-resolution data capabilities at an intersection, CoA staff are required to install the necessary hardware at an intersection to collect data and implement the corresponding software system to manage the data. Compatible controllers (e.g. D4 controllers) are already capable of natively logging this information and saving it to a CoA database. The CoA currently has access to high-resolution data at approximately 214 intersections across the city. Figure 2 shows the high-resolution data coverage across the city where the numbers in the figure represent locations with multiple intersections collecting data in that area.

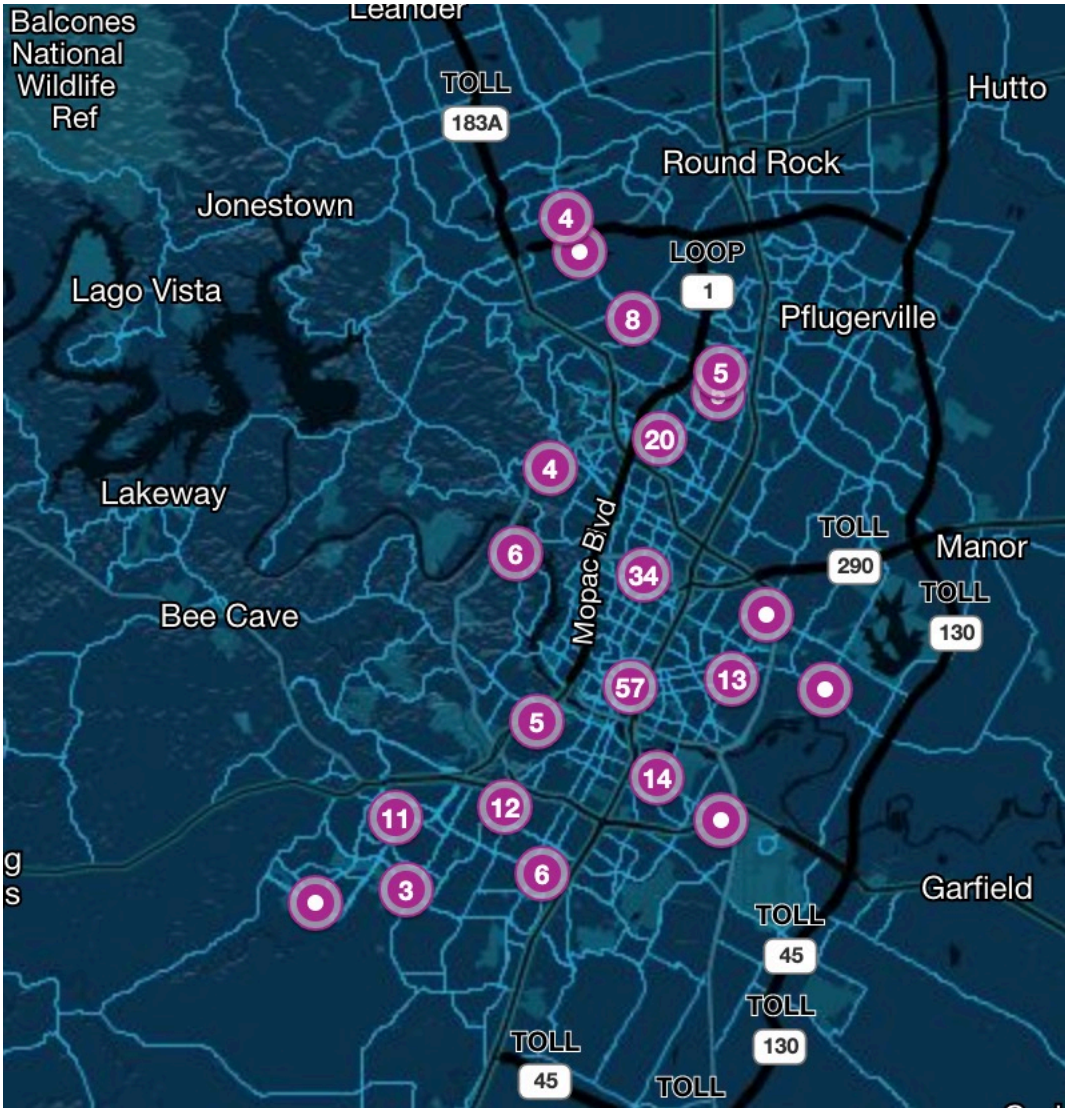

Figure 2: Map of High-Resolution Data Coverage for the City of Austin (Kimley-Horn)

Kimley-Horn manages the online dashboard used to display corresponding metrics (Automated Traffic Signal Performance Measures or ATSPMs) from the high-resolution data for the CoA. The CoA's online dashboard for visualizing high-resolution data makes use of these ATSPMs, which are developed performance metrics that are specific to traffic signal performance. Chapter 3 will review the literature surrounding these performance metrics in more detail. The dashboard provides the capability to generate visualizations of individual metrics at individual intersections as well as generate visualizations of aggregated ATSPM data of multiple intersections to summarize corridor signal performance. While the benefit of the online dashboard is that it simplifies highly complicated and dense high-resolution data into more digestible ATSPM visualizations, the online dashboard is less flexible in allowing users to specify input parameters such as non-consecutive dates of interest and in processing the high-resolution data, which limits the vast number of metric options that are possible to explore with raw high-resolution data. Thus, attempts have been made to gain access through the CoA and Kimley-Horn to raw high-resolution data through the CoA's SQL server to supplement the ATSPM information available on CoA's online dashboard for future research work.

CoA also expressed interest in exploring Automatic Vehicle Location (AVL) and Automatic Passenger Count (APC) data for development of metrics regarding transit travel time and/or transit ridership to incorporate a multi-modal aspect to the evaluation. AVL data provides transit vehicle locations at frequent intervals by relying on the communication of individual bus technology with GPS satellites (OSU, 2019). APC data provides a count of boarding and alighting transit passengers for each vehicle by relying on automatic passenger counters that count people as they pass through electronic infrared beams or step on mechanical mats (NCTR, 2010).

APC data also provides dwell times at bus stops, which could be subtracted from AVL derived travel times to obtain an in-motion travel time for buses. Currently, the AVL data that is accessible through Capital Metro Transportation Authority (CapMetro), Austin's public transportation provider, provides streamed updates at 2-minute intervals, which is not precise enough for the sub-section travel estimates that are involved in retiming evaluation processes. However, CapMetro is in the process of updating their provided feeds to stream their vehicles' capability to send location information approximately every 10 seconds. In addition, APC data is currently posted online by CapMetro only once every service period. This is due to the APC data containing a large number of records that makes frequent data uploading infeasible. CapMetro elects to wait until after a service period before uploading its corresponding APC data in order to finalize any changes that must be made to the count data during a service period. These limitations stalled efforts regarding transit focused metrics, but future efforts on this project will work towards retrieving AVL and APC data sufficient for CoA research purposes.

2.3 SUMMARY OF EXISTING COA EVALUATION PROCESS AND DATA SOURCES

The CoA currently relies on a retiming evaluation process that solely considers corridor travel time difference as measured by floating car runs conducted on a single day before and after retiming. With a variety of data sources available, there is great potential for CoA to utilize alternate sources of travel time data such as INRIX and Traction in place of variable floating car run samples. In addition, other data sources are capable of providing corridor performance information other than travel time, such as traffic volumes, split failure information, transit vehicle locations and transit vehicle passenger counts that present an opportunity for supplemental performance metrics to be developed and incorporated into the CoA’s retiming evaluation process.

Chapter 3: Review of Literature

The academic literature review for this project focused on both determining the variety of performance metrics used in practice by other agencies for the purpose of evaluating signal retiming efforts and exploring the types of information that can be extracted from available data sources. In particular, extensive literature surrounding the use of high-resolution data and corresponding ATSPMs that describe the data was reviewed given their relative novelty to CoA staff.

3.1 RETIMING EVALUATION PERFORMANCE METRICS

While there is a large amount of literature regarding performance metrics that are used to help engineers with the retiming process itself, it is interesting to note that less literature was found that investigated performance metrics for the express purpose of evaluating the effect of retiming efforts. It is evident that while many agencies have defined performance metrics for evaluation of signal performance, the area of evaluating the impact that the work of signal retiming had on traffic operations through before-and-after comparison is a less explored field of research. Thus, the few performance measures discussed in this chapter are a sample of those that were identified as being feasible for application toward before-and-after retiming comparison.

When developing signal retiming measures for the purpose of evaluating retiming efforts, Gordon and Braud (2009) indicate that it is important that the data required for these metrics be comprehensively available across an agency's regional jurisdiction. This ensures that an agency has the benefit of understanding the retiming effects of individual corridors when compared in relation to other corridors in the region. Gordon and Braud also maintain that retiming metrics should quantitatively describe performance in a manner which minimizes or eliminates the need for subjective human judgement to interpret the results (Gordon & Braud, 2009).

Control delay, or total delay at an intersection, was a commonly found signal retiming evaluation metric used for evaluation of coordinated signals. By using multiple data sources to compute control delay for a test corridor, researchers found specific strengths of and/or issues with data sources such as high-resolution data, Bluetooth/Wi-Fi data, and segment-based probe vehicle data (such as INRIX). For example, the Purdue Coordination Diagram generated from high resolution data was found to be helpful in identifying coordination issues quickly and aiding engineers in optimizing the corridor afterwards. On the other hand, Bluetooth/Wi-Fi data as visualized through cumulative frequency diagrams was determined to be helpful with identifying coordination issues but less useful for adjusting offsets. Finally, segment-based probe vehicle data made it difficult to identify issues at specific signals due to the segment-based nature of the data that often can encapsulate multiple intersections in a single segment (Remias et al., 2018)

Another metric identified through literature review was maximum vehicle delay, or the maximum waiting time experienced by any vehicle during a single cycle, as measured by the waiting time for the first arriving vehicle on red. Researchers point out that while minimizing control delay is a valuable metric for determining if an intersection is oversaturated, Lavrenz et al. point out that individual drivers at intersections with low average delay may still experience long waiting times (Lavrenz et al., 2015). Thus, maximum vehicle delay offers a means of measuring the worst-case scenario delay. This metric could potentially be used to characterize an entire intersection by weighting the average maximum vehicle delay observed on every individual phase (Lavrez et al., 2015). In Austin, CoA staff pointed out that many drivers check their phones during red intervals and will often increase their delay time by missing the first few seconds of green due to distraction. Thus, development of this metric was not pursued due to concern that driver behavior would negatively influence any observed results.

Some other performance metrics that were discussed in literature were safety with regard to crash rates at intersections and/or causes of crashes, fuel consumption, and emissions (which would require fuel consumption information to determine) (NCHRP, 2010). Since the capabilities of high-resolution data include red-light runs, safety could be a future feasible performance metric for the City of Austin. In addition, an example in the literature is provided of one model for fuel consumption that relies on total travel distance, total delay, and number of vehicle stops. This model assumes specific vehicle types and engine technologies to be in use which are not necessarily representative of current technologies but could be useable for the purposes of before and after retiming comparison studies (NCHRP, 2010).

3.2 REVIEW OF DATA SOURCES

To assess the quality of retiming efforts, many agencies conduct floating car runs to obtain before and after travel-time data. However, these can only provide brief time snapshots and are too labor-intensive to adopt as a method for obtaining system-level metrics. Floating car studies also inherently emphasize arterial progression over other important objectives such as side street performance (Day et al., 2015).

Real-time status displays (e.g. traffic video feeds) are a monitoring solution for assessing performance and are useful for detailed spot-checking. However, monitoring these displays requires manual observation and is therefore not a performance assessment method that can independently and systematically identify issues (Day et al., 2015).

High resolution data and corresponding ATSPMs in particular are fairly new contributions to the field of traffic signal performance metrics that are powerful in their combination of dense data with meaningful interpretation and visualization. ATSPMs were initially developed in 2005 in Indiana, where researchers and a group of vendors proposed a package of performance measures that analyzed and visualized high-resolution logged events to characterize useful measures for agencies to operate and maintain their signals (Bullock et al., 2014). Currently, around 26 state and local level transportation agencies have implemented or are in the process of implementing ATSPMs (Curtis & Denney, 2019).

For most agencies deploying high-resolution data, their ATSPMs include some combination of the following twelve performance metrics (Curtis, 2018):

1. Purdue Coordination Diagram (PCD)
2. Purdue Phase Termination
3. Purdue Split Failure
4. Approach delay
5. Approach volume
6. Arrivals on red
7. Pedestrian delay
8. Preemption details
9. Split monitor
10. Turning movement counts
11. Yellow and red actuations
12. Approach speed

These twelve measures are usually analyzed by agency personnel through graphical visualization. Developed as an analysis tool by Purdue and INDOT researchers, the PCD shows vehicle arrivals for every movement of a cycle relative to the green, yellow, and red phases

(Atkins North America, 2016). The PCD as shown in Figure 3 helps agencies detect platoons of vehicles, assess the quality of their progression along an arterial, and make changes to offsets if necessary.

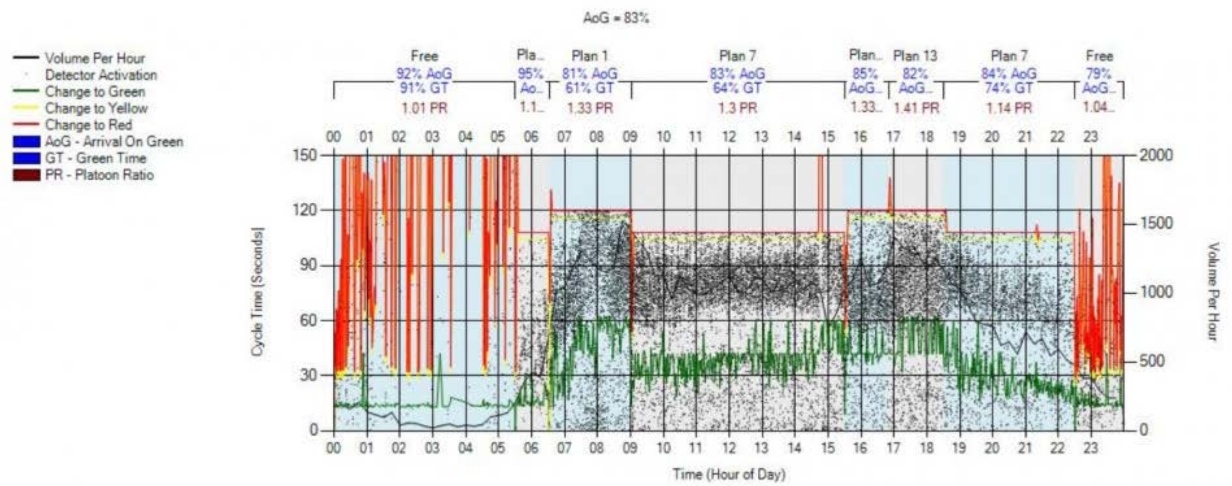

Figure 3: Example of Purdue Coordination Diagram (UDOT)

The Purdue Phase Termination chart is another tool shown in Figure 4 that graphically displays the reason for every phase's termination during any time period of the agency's choosing (Atkins North America, 2016). This phase termination information can assist agencies in optimizing split times and identifying any possible broken detectors.

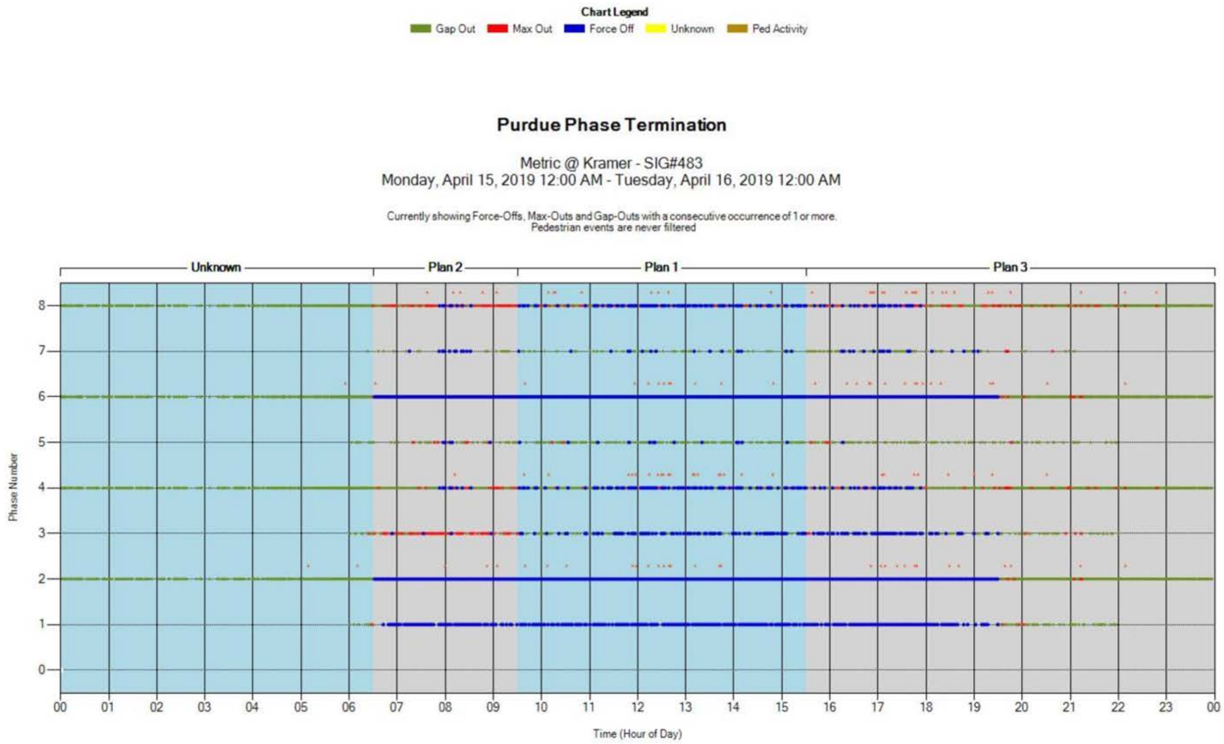

Figure 4: Example of Purdue Phase Termination Chart (UDOT)

The Purdue Split Failure chart is shown in Figure 5 and displays the green and red occupancy ratios for detectors for one particular phase of interest at a time. If both ratios are greater than eighty percent for a specific phase, that cycle is said to have had a split failure (Atkins North America, 2016). This analysis tool allows agencies to determine if vehicles are waiting more than one cycle length to be served and assess if phase changes need to be made to push a greater capacity of vehicles through the intersection. Although they possess similar names, the Purdue Split Failure chart is not to be confused with the split monitor chart, which measures the red, yellow, and green split times used at each phase of an intersection (UDOT, n.d.).

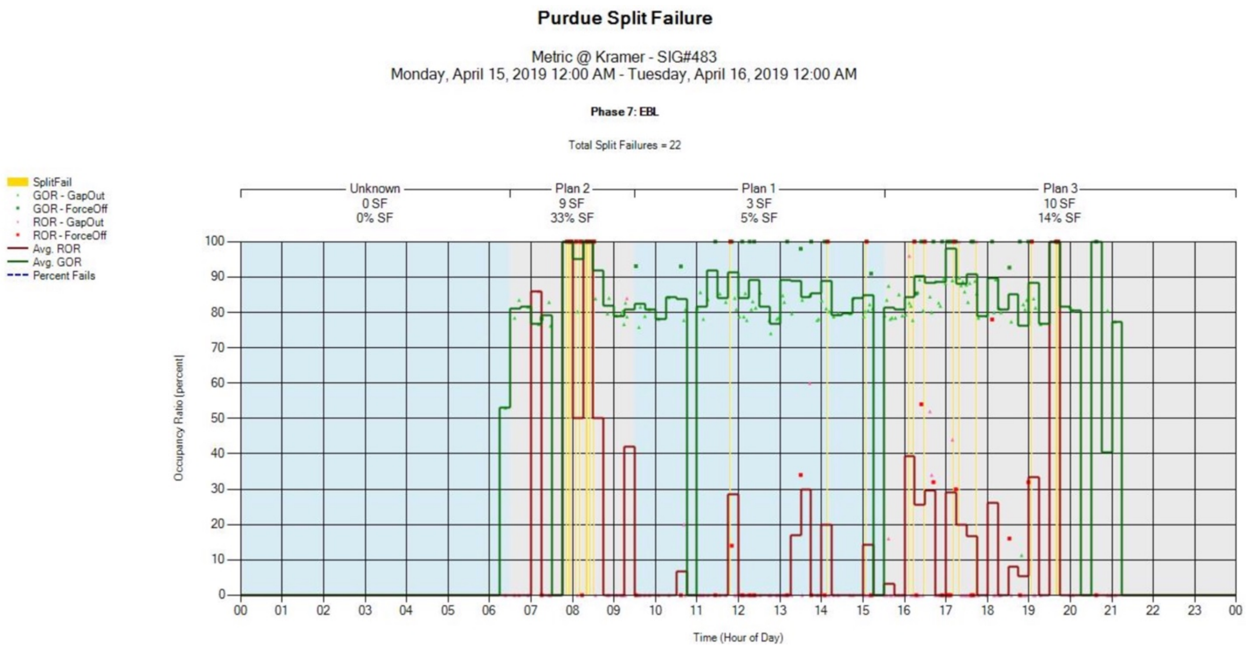

Figure 5: Example of Purdue Split Failure Chart (UDOT)

According to a usage report from Utah Department of Transportation (UDOT) that summarized the usage reports for its performance measures/graphical visualizations for a six-month period in 2017, the most used metrics among its personnel were the Purdue Phase Termination, the split monitor, and the Purdue Coordination Diagram respectively. Conversations with UDOT staff further revealed that the Purdue Phase Termination tool is primarily used to address complaints on an operational level, the split monitor tool for troubleshooting, retiming, and other general purposes, and the Purdue Coordination Diagram for analyzing cycle lengths and determining if general retiming is needed (Day et al., 2015). Currently, Austin's ATSPM web interface (developed by Kimley-Horn), provides the functionality for agency staff to select a signal, performance metric, and date range of interest and immediately receive a performance output.

3.3 HIGH-RESOLUTION DATA COLLECTION REQUIREMENTS

There are several data collection requirements for the generation of ATSPMs. Agencies first must ensure that their cabinet types are capable of logging high-resolution data. Several vendors have developed this compatibility with NEMA TS-2 Type 1, NEMA TS-2 Type 2, ATC 170, and ATC 2070 cabinet standards (Day et al., 2015). In the past, signal controllers provided limited data (volume and occupancy measurements aggregated into long time bins) and required more advanced external control applications if engineers desired to obtain more detailed information. Now, signal controllers are able to develop detailed datasets within themselves. There are several vendors that offer controller models that support high-resolution event data logging (Day et al., 2015).

With the various types of detection technology available (e.g. inductive loop detectors, video, infrared sensors, and radar) the type of detection does not significantly impact the high-resolution data logging process as long as it can record vehicle detection and/or count information. In fact, detection is not necessary if a controller has high-resolution data logging capabilities since an agency can still monitor phase timings and status codes (Day et al., 2015). While early high-resolution data studies were conducted with inductive loop detection, UDOT utilizes radar detection and in some parts of Indiana, video detection is used with no impact on high-resolution data collection. The Indiana Department of Transportation (INDOT) even developed criteria to specify their acceptable baselines for detector performance to assist in their selection process (Day et al., 2015). With regards to determining the position of in-pavement detection, literature states that lane-by-lane detection is ideal and recommended as the configuration of choice for intersections where there is differing vehicle behavior between lanes since it provides much more detailed information than cross-lane detection. In addition, stop bar detection and advance (setback) detection have phase actuation applications and can be used separately or in conjunction at intersections to provide applications such as dilemma zone protection, detection of queues, and counting arrivals (Day et al., 2015).

3.4 IMPROVEMENTS TO HIGH-RESOLUTION DATA COLLECTION/QUALITY

Practitioners that utilize ATSPMs have pointed out that these measures have few data quality checks in place to verify the raw data feeds that it receives from controllers. To address this shortcoming and a host of others, Huang et al. proposed a new tool, the Intelligent Traffic Signal Performance Measurement (ITSPM) system, which makes use of machine learning and other techniques to propose improvements to sensor and communication health (Huang et al., 2018). The ITSPM tool assists agencies in detecting both logging failures and sensing errors. Ideally, an agency’s signal controller will generate a logging flag at known intervals so that by counting, personnel can identify if any flags are missing, revealing a logging failure. If this controller feature is not present, ITSPMs offer two measures that track logging failures. One of these measures is the “Spurious Inactivity Period,” in which logging gap distributions help determine a time threshold for distinguishing between spurious inactivity and normal inactivity during periods when a controller records no event codes. Huang et al. defined a time threshold of 300 seconds in their study using one week of intersection data from Portland, OR (Day et al., 2015). Another logging failure measure is the “Missing Event Error,” during which a controller spuriously skips a single event code for some interval of time. Usually certain event codes should occur in pairs, such as the phase statuses that indicate the start and end of a green phase. To identify the cases where a controller is spuriously skipping a code, ITSPM generates tick marks for each instance that expected pairs of event codes do not accompany each other and creates histogram summaries of these missing errors for operators to easily interpret (Day et al., 2015). ITSPMs can also detect sensor errors that manifest in stuck call and false call errors. For stuck call errors, an agency can define the parameter that is used as a threshold for detector occupancy, beyond which ITSPMs will label a call as a sensor error. Huang et al. define a threshold of six minutes, which means that a flag will be raised if a detector is occupied for more than two back to back cycles of a conservatively estimated 180 seconds (Day et al., 2015). False call errors are defined as instances when the saturation flow rate is exceeded by one detector per lane over a one-minute period. Agencies are advised to use engineering judgement to ascertain an appropriate threshold saturation flow rate. Huang et al. use a 2,700 vehicles per hour per lane value as their threshold, above which ITSPM records a false call error (Day et al., 2015). Finally, the ITSPM tool plots a scatter plot of vehicles per minute per lane against time occupancy in minutes. After identifying these two sensing error thresholds, it is easy to quickly identify the calls plotting above the horizontal threshold saturation flow rate per lane as false calls and the calls plotting above the vertical time occupancy threshold as logging errors/stuck calls. With this visual, agencies can assess the performance of detectors over time and identify if maintenance or repair is needed. Performing these quality control checks on high-resolution data before making any decisions will ensure that ATSPMs are providing accurate information.

3.5 IMPROVEMENTS TO ATSPM ANALYSIS POSSIBILITIES

While ATSPMs offer agencies the powerful ability to analyze signal system performance over time to assess long-term changes, they have several limitations pertaining to their analysis functionality. One shortcoming pointed out by Huang et al. is that ATSPMs are mainly focused on automobile traffic and offer no multimodal information other than pedestrian delay. UDOT is in the process of adding Transit Signal Priority as another ATSPM metric to enable agencies to analyze transit delays and investigate the performance of the prompted transition phase when TSP is utilized (Day et al., 2015). UDOT engineers also suggested that ATSPMs could benefit from greater spatial resolution and identified a need for improvement in its capability to examine operational performance beyond individual intersections and into a greater corridor/system-wide level (Day et al., 2015). In 2018, Day et al. addressed this need by proposing a prototype of a data-driven method that simplifies the individual intersection analysis process to one that compiles data into digestible performance scores for corridors. This method developed sub-scores based on communication, detection, safety, capacity allocation, and progression for eight Indiana corridors and assigned an overall corridor score based on the lowest sub-score (Day et al., 2018). Individual agencies might choose to adapt the specific sub-scores to their own performance objectives, but the proposed method serves as an improvement for agencies desiring to expand their ATSPM functionalities.

3.6 SUMMARY OF LITERATURE REVIEW

The majority of relevant literature was found to pertain to the process of signal retiming itself rather than the before-and-after comparison of the process' effects. Nevertheless, a few performance measures including control delay, maximum vehicle delay, safety (crash rates and/or causes of crashes), fuel consumption and emissions were identified as metrics that were potentially applicable for before-and-after retiming comparison studies. A review of high-resolution data and its corresponding ATSPMs also revealed that some of the most popular metrics derived from this data source among transportation agencies include the Purdue Phase Termination, split monitor, and Purdue Coordination Diagram. These and several other ATSPMs are available to the CoA through a web interface that provides a graphical user interface for analyzing the performance of available intersections across the city. While there are still many future improvements needed to high-resolution data quality, this data source in particular was determined to provide an extensive amount of data and pre-defined metrics that could be applied towards retiming evaluation efforts.

Chapter 4: Development of Metrics for Retiming Evaluation

After reviewing the relevant literature and based on the availability of data sources, six metrics were developed that together met the CoA's primary objectives of considering other non-vehicular modes and the effects on side-street performance. These metrics included corridor travel time change, corridor throughput, side street split failures, pedestrian delay, transit speed change/transit ridership change, and reliability index change. The following sub-sections will describe and quantify the developed performance metrics as well as outline the steps taken to obtain desired metric values from their respective data sources.

4.1 PERCENT END-TO-END CORRIDOR TRAVEL TIME REDUCTION

Historically, the CoA has relied on a series of floating car runs as the primary if not only data source for their percent travel time reduction metric. The strength of travel time runs is that they reflect the "typical" driver's experience during the time which they are conducted. However, these runs are usually conducted on a single day before and after retiming, yielding a relatively small sample size of vehicle runs that is highly subject to random variation affecting the metric's accuracy. Given that the CoA had access to new travel time data sources (INRIX and Traction) that provide a wealth of historical data, a similar methodology to the one used currently by the CoA was developed for calculating percent travel time reduction using both INRIX and Traction. A comparison analysis between the three different travel time data sources was also conducted on a CoA corridor to investigate the nuances of each data source when applied in a similar way. This is discussed below in a later section.

The process for INRIX data acquisition was documented in a previous iteration of this project and a similar process was conducted for the retiming evaluation where data was defined and downloaded from the INRIX Analytics web-based interface at fifteen-minute granularity, making sure to specify only segments corresponding to retiming intersections and date ranges corresponding to the before and after analysis period of interest (Dunn, 2018). Figure 6 shows an example of the INRIX interface used to download data for Oltorf St. in Austin.

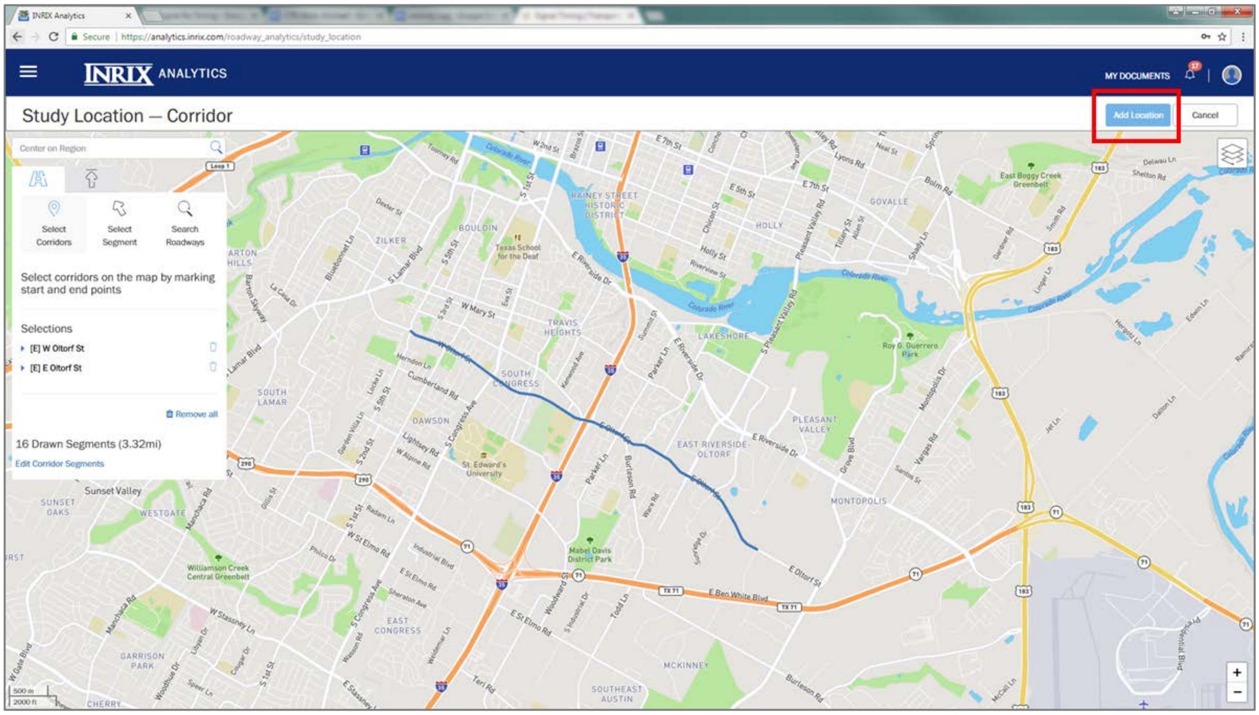

Figure 6: Example Web Interface for INRIX data acquisition from Oltorf St. (Dunn, 2018)

Using Excel, the raw data was then transformed in several ways to produce final travel time reduction values as well as visualizations of travel time plots depicting the average 15-min travel time over 24 hours across both the before and after analysis periods. Segment travel time data was first aggregated into corridor travel times for both directions of travel. Then travel times across all days in both the before and after comparison periods were averaged for each fifteen-minute timestamp between 12:00 AM and 11:45 PM, resulting in ninety-six travel time average values for each corridor's direction. These values could then be plotted to visually represent the average distribution of travel time before and after retiming occurred. In conjunction with a final percent travel time reduction metric value, these plots help CoA staff quickly characterize corridor flows at specific time periods. Since the CoA was interested in determining if variation existed between the three travel time data sources, these plots were also used to compare if and how travel time differed between INRIX, Traction, and travel time runs for the same time periods. To calculate a final corridor percent travel time reduction metric value, the percent difference between the before and after retiming total sums of all fifteen-min average travel time values on a corridor can be calculated. For the sake of equivalent comparisons, only a portion of the twenty-four-hour INRIX average travel time data that corresponded with when runs were conducted were used to calculate metric values. However, the CoA has the flexibility with both INRIX and Traction data to include travel time data from all times of day in their analysis.

Traction data is less reliable than INRIX data as some fifteen-min intervals do not contain travel time information. However, Traction crowd data reports in a similar format to INRIX and thus was treated in much the same way as INRIX data to yield an average travel time plot and a percent travel time reduction value. As shown in Figure 7, the CoA already monitors several corridors through Traction’s web-based interface and pre-defines the start and end bounds for those corridors.

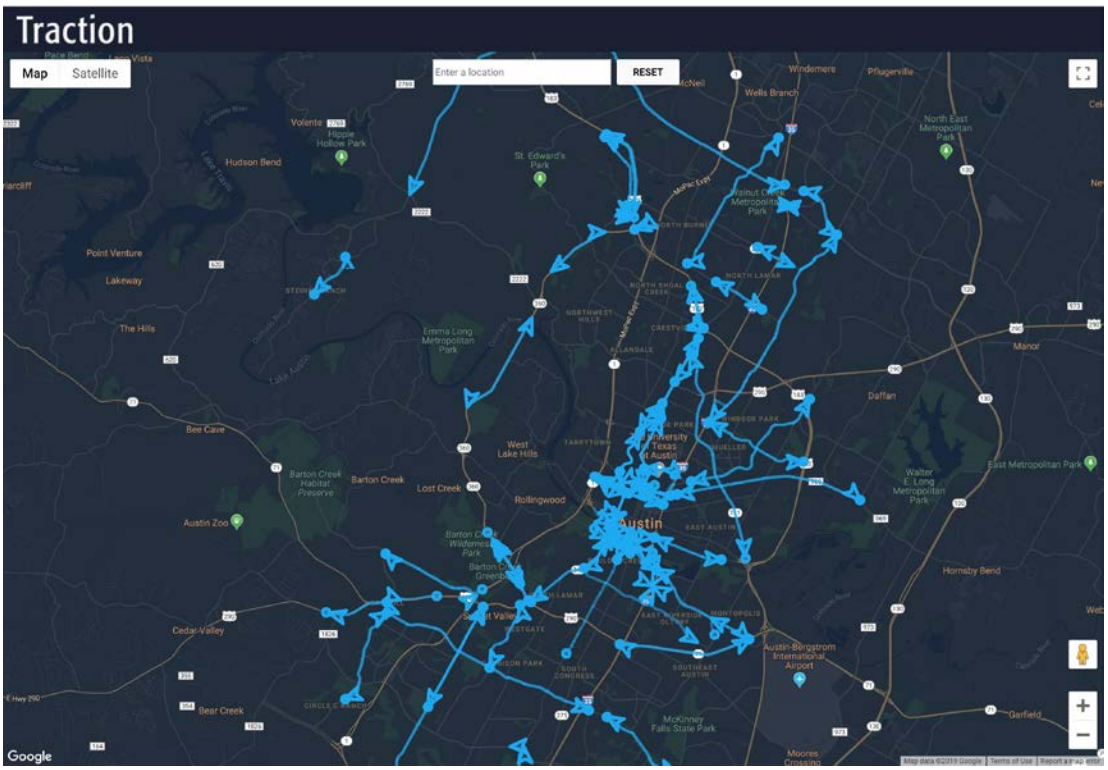

Figure 7: Kimley-Horn’s Web Interface for Traction in Austin (Kimley-Horn)

4.2 EXITING THROUGHPUT VOLUME

In order to obtain a sense of the number of vehicles being served at intersections along a corridor, an exiting throughput volume metric was developed that provides the total vehicular volume exiting each intersection along a corridor’s main street. Given an intersection along an eastbound/westbound corridor, Figure 8 shows the four approach volumes (SB Right, NB Left, WB Through, EB U-Turn) that are summed together to result in a WB exiting throughput volume and the four approach volumes (NB Right, SB Left, EB Through, WB U-Turn) that are summed together to result in an EB exiting throughput volume. The same method can be applied to a northbound/southbound corridor as well.

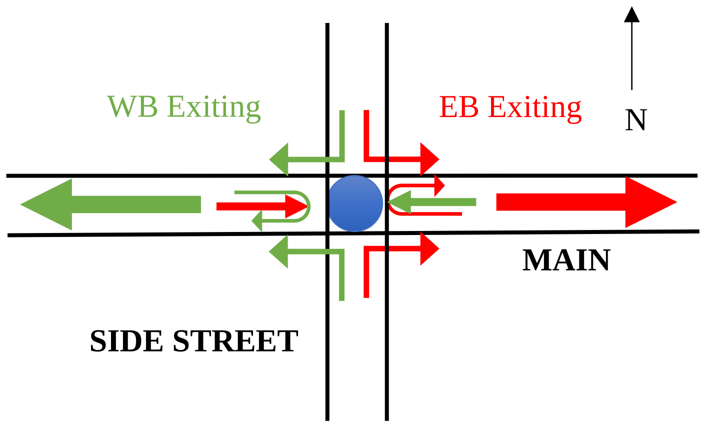

Figure 8: Diagram of Approaches Comprising eastbound/westbound Exiting Throughput Volume

Obtaining this final metric from raw GRIDSMART data involved a few data processing steps. First, a previously compiled Python script was used to aggregate GRIDSMART data into fifteen-minute turning movement counts. These turning movement counts were then ingested into a PostgreSQL (PSQL) database along with a table specifying the movements comprising each exiting throughput value (i.e. Figure 8). By joining these two tables together, exiting throughput volumes were produced for a set of intersections at fifteen-minute intervals across a set of days. Then, fifteen-minute volumes were summed together to create hourly volumes, which were then averaged across all weekdays in each before-and-after retiming dataset to arrive at average hourly exiting throughput volumes for each intersection. These hourly volumes could then be plotted to visualize the change in volume throughout a day and they could also be summed to result in a final average exiting throughput volume for both directions of an intersection along a corridor.

4.3 SIDE STREET SPLIT FAILURE CHANGE

Using split failure information derived from high-resolution data, a side street metric was also developed to evaluate the effect of signal timing changes upon vehicles entering a corridor along its side streets. Split failures are events that high-resolution data compatible controllers mark as occurring when a phase's green occupancy ratio exceeds 80 percent and its red occupancy ratio of the first five seconds also exceeds 80 percent. When split failures occur, this informs CoA staff that at those places and times, green signal time failed to meet vehicle volume demand.

Since Kimley-Horn's online ATSPM dashboard already allows the CoA to visualize plots of aggregated split failures, effort was invested into creating quantitative split failure metric values that characterized the changes in side street performance due to retiming. To bypass the labor-intensive step of filtering raw high-resolution data into relevant split failure information, the aggregator capability developed by UDOT that gave Kimley-Horn the ability to provide fifteen-minute aggregated split failure data was used. Using this data in Excel, split failures occurring on the side streets were filtered out from those occurring on the main corridor street and the 15-minute split failure event counts were summed into hourly split failure counts for each day. Then, hourly counts across all intersections on a corridor that fell into the CoA's typical time-of-day (TOD) ranges (7-9 AM, 12-2 PM, 4-6 PM) during weekdays of interest were summed together to create three TOD split failure counts, which were then divided by the number of days in the dataset to result in an AM, Off-Peak (OP), and PM average daily count of split failures. By doing this for both the before and after retiming cases, it was then possible to compute a percent change in average number of daily split failures. While the developed metric focuses on side streets, the same analysis was also conducted on the corridors' main street to investigate the underlying assumption that retiming often favors main corridor performance over side street performance.

4.4 PEDESTRIAN DELAY CHANGE

High-resolution data also provides multi-modal data in the form of pedestrian delay information. Given that the CoA was interested in expanding the retiming evaluation process to include other modes, a pedestrian delay change metric was also developed. UDOT's ATSPM software obtains pedestrian delay by computing the time occurring between a push button actuation and the beginning of the corresponding pedestrian phase. However, if a pedestrian does not push the pedestrian button at an intersection, their experienced delay is not captured by the controller. Currently, UDOT's ATSPM software does not provide the same aggregator functionality for its pedestrian delay as it does for split failures. This means that in order to obtain delay data containing every pedestrian actuation and its associated delay for a specific time period/number of intersections, one would have to extract that information from raw high-resolution data files by identifying all pedestrian actuation events and pedestrian "Begin Walk" events and subtracting the difference in their timestamps. Currently, Kimley-Horn provides small samples of high-resolution data files upon request. However, extracting pedestrian delay information for an entire corridor over weeks of before/after retiming analysis would require a high volume of raw data, necessitating access to the CoA's high-resolution SQL database. While this access issue was being addressed by CoA staff, a single raw high-resolution data file was requested for a single intersection on a single day to develop a metric to be used in the future when more data was accessible. For every timestamp in the data file, there was an event code and event parameter code provided for the intersection. These event codes symbolize the occurrence of different events occurring on a traffic signal controller (e.g. detector, preemption, etc.) and the event parameter codes usually specify the corresponding phase.

Using this small sample of raw high-resolution data, the data was filtered to obtain all "45" and "21" event codes (and their associated parameter codes). Event codes labeled as "45" translate to the controller registering a pedestrian call, and event codes labeled as "21" translate to the beginning of a pedestrian walk phase. By ordering the occurrence of these paired events happening in sequence ("45" followed by "21") in the data file and subtracting their timestamps, the pedestrian delays experienced were derived. Using Excel, it was then possible to calculate a variety of statistics such as average daily pedestrian delay. After weighing the merits and drawbacks of using statistics like average delay, median delay, or even maximum delay, an 85th percentile delay metric was chosen to provide the best summary of variation in pedestrian delay in a single value. Although there was insufficient raw data to analyze a full before/after retiming scenario, this eighty-fifth percentile metric can be calculated in the future for both a before and after case and taking the percent difference of the resulting percentile values.

4.5 TRANSIT VEHICLE SPEED CHANGE

While waiting on APC data and higher resolution AVL data, an initial foray into developing a transit vehicle speed change was conducted using low-resolution (locations streamed every 2 minutes) AVL data. To compute average transit speed on a corridor based on AVL data, an ArcGIS shapefile containing corridor geometry for all CoA retimed corridors of interest was first created and then AVL points were matched to these corridors. Since the low-resolution data has 2-minute location intervals, it is likely that for any two bus location points, the distance covered in between may only cover a portion of a corridor. Thus, a requirement that 35 percent or more of the corridor must be covered by two AVL points to be included as a bus speed data point in the dataset was set. In the future when high-resolution data is provided, this will be less of a concern since it will be easier to discern which segment(s) of the corridor are covered by an individual bus during which timestamps.

Using previously developed R code for AVL speed processing, a transit average speed plot was generated for a 24-hour timespan along a corridor during both a before/after retiming case. Future work on developing more accurate plots using higher-resolution data will inform how to distill these plots into a final transit vehicle speed change metric value.

4.6 RELIABILITY INDEX CHANGE (PEAK BUFFER INDEX ACROSS DAYS)

Using INRIX travel time data, two FHWA reliability metrics (Buffer index within day, and buffer index across days) were developed to evaluate reliability changes due to retiming. FHWA defines a buffer index to be "the extra buffer time that most travelers add to their average travel time when planning trips to ensure on-time arrival" by accounting for unexpected delay or unreliability (FHWA, 2017). This buffer index is calculated by subtracting the average travel time from the 95th percentile travel time and dividing the result by the average travel time. Thus, higher buffer indices translate to worse reliability along a corridor. Buffer index within day and across days represent the variability of travel time within a day and across days for a selected 15-minute time period respectively. After discussion with CoA staff, it was agreed that within day variation can be attributed more to large changes in travel demand than signal retiming effects that are within CoA control and thus a buffer index across days metric would be a better measure of reliability for the purposes of this project.

To calculate this buffer index, INRIX data that was already ingested in a PSQL database was used to compute average total corridor travel times at 1-hour intervals for each corridor and then one buffer index per hour for each corridor was calculated. These resulting 24 buffer indices could be visualized for every corridor and reported as a range or as the observed buffer index during peak travel times. To supplement the app, the buffer index values were then reported for both the before/after cases for each corridor in a table to compare retiming effects. Future work could include adding corridor length information and "typical travel time" estimates for each corridor to provide more meaning to the buffer index value.

4.7 SUMMARY OF RETIMING EVALUATION PERFORMANCE METRICS

Six performance metrics were developed using a combination of INRIX/Traction, high-resolution, AVL, and GRIDSMART data. Percent end-to-end corridor travel time reduction was retained as an evaluation metric but was improved upon by the incorporation of INRIX and Traction data in addition to previously used floating car run data. By accessing historical data through these two probe-vehicle data sources, average travel time plots were developed that provided the added benefit of including travel time effects from all days within the before-and-after study periods. GRIDSMART data was used to develop an exiting throughput volume metric that quantified the total vehicular volume passing through an intersection along a corridor's main street. Provided that the CoA increases the availability of GRIDSMART data around the city, this metric has promising potential for supplementing the traditional corridor travel time metric by providing information on the effect of retiming on vehicular throughput. High-resolution data was utilized to develop additional side street split failure change and pedestrian delay change metrics. The split failure metric allowed the CoA to determine if and how retiming efforts favor main street performance at the expense of side street performance. The pedestrian delay change metric quantified the effect of retiming on the 85^{th} percentile pedestrian experienced delay. In addition to considering pedestrians, a preliminary metric for transit vehicle speed change was also developed to further improve the multimodal aspects of the retiming evaluation. Low-resolution AVL data was tested to generate transit average speed plots for a corridor during a before-and-after retiming scenario. INRIX data was also used to develop a reliability index change metric that utilized a FHWA defined buffer index to quantify observed travel time variability across days due to retiming. Together, these six metrics quantitatively evaluate the effect of retiming on multiple aspects of vehicular travel as well as multiple modes of travel along corridors in Austin to form a more holistic evaluation process.

Chapter 5: Applying Developed Metrics to 2019 Retimed Corridors

During the course of this project, CoA was in the process of retiming several corridors including Metric Blvd., W Parmer Ln., West Gate Blvd., and Escarpment Ln. Figure 9 shows the four test corridors as well as the data availability along those corridors. Most of the performance metric development was applied using Metric Blvd. since it was the only corridor that had been retimed at the time of analysis (Metric Blvd. was retimed during Spring 2019). W Parmer Ln. was also initially scheduled to be retimed with Metric Blvd. during Spring 2019, but its retiming was pushed back to a later time. However, due to the availability of GRIDSMART data at several intersections along W Parmer Ln., exiting throughput volumes were still calculated for the selected before period used for the Metric Blvd. analysis. West Gate Blvd. and Escarpment Ln. were retimed during Summer 2019 but due to ongoing issues with retrieving high-resolution data from those corridors, these corridors were not analyzed with the developed performance metrics.

The remainder of this section will illustrate the results of the six previously defined and discussed metrics as they were applied to any of these four test corridors. Appendix A summarizes the final metric values for the retimed corridors with individual corridor fact sheets.

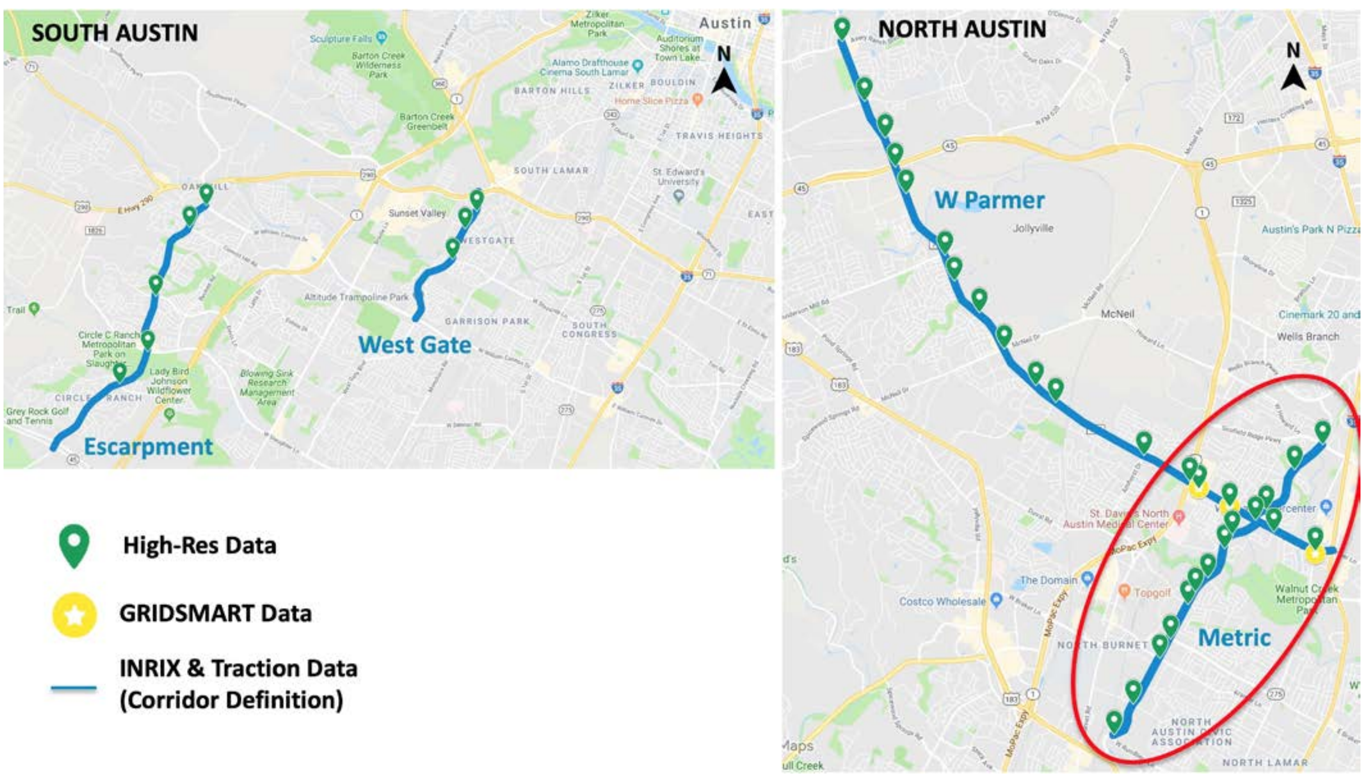

Figure 9: Map of Corridors & Corresponding Data Availability (Google Maps)

5.1 PERCENT END-TO-END CORRIDOR TRAVEL TIME REDUCTION

For this analysis of travel time reduction along Metric Blvd., a two-week period before and a two-week period after retiming were compared using INRIX and Traction. Metric Blvd. was retimed in early April, so the before period was selected to be March 4th-March 14th (excluding Fridays and weekends), and the after period to be 5/6/19-5/9/19 as well as 5/20/19-5/23/19. Two after periods were selected to avoid UT Austin's spring break at the end of March. It should be noted that the after period coincides with UT Austin's end of classes, and thus corresponding abnormal traffic patterns, but given the date of retiming, the time period chosen in May was the best option. Figure 10 shows the comparison of resulting travel time plots along Metric Blvd. before and after retiming occurred. While it is difficult to conclude the travel time change along Metric Blvd. due to retiming from these plots, they are much more useful to compare the travel time differences reported by the three data sources. Based on Figure 10 during the off-peak times, both INRIX and Traction tend to similarly overestimate the travel time experienced on manual runs. However, during some of the peak travel times as seen in the northbound direction, both INRIX and Traction are underestimating the travel time experienced by the manual runs (although Traction does a better job than INRIX). Given that both INRIX and Traction conduct pre-processing that results in data smoothing, it is suspected that an averaging effect might be occurring, so the worst travel times may not be reported from these sources.

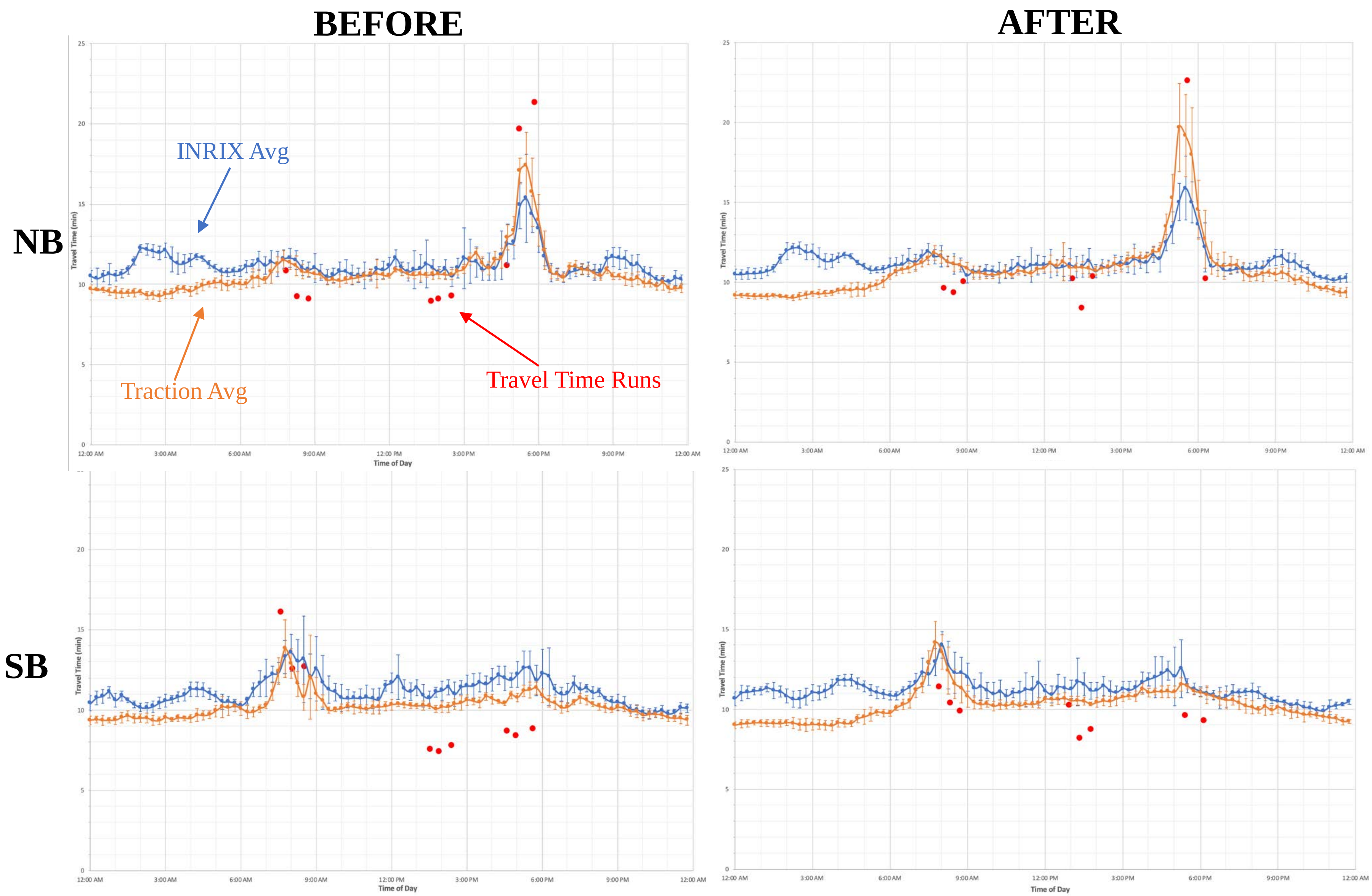

Figure 10: Average 15-Minute Travel Time Plots for Metric Blvd using INRIX, Traction and Travel Time Runs

To confirm these suspicions, the same travel time plots for eight other CoA corridors excluding manual floating car travel time runs were also created. Figure 11 shows the generated plots. The corridors and the two-week time period shown were chosen based on Traction data availability during the month of the analysis.

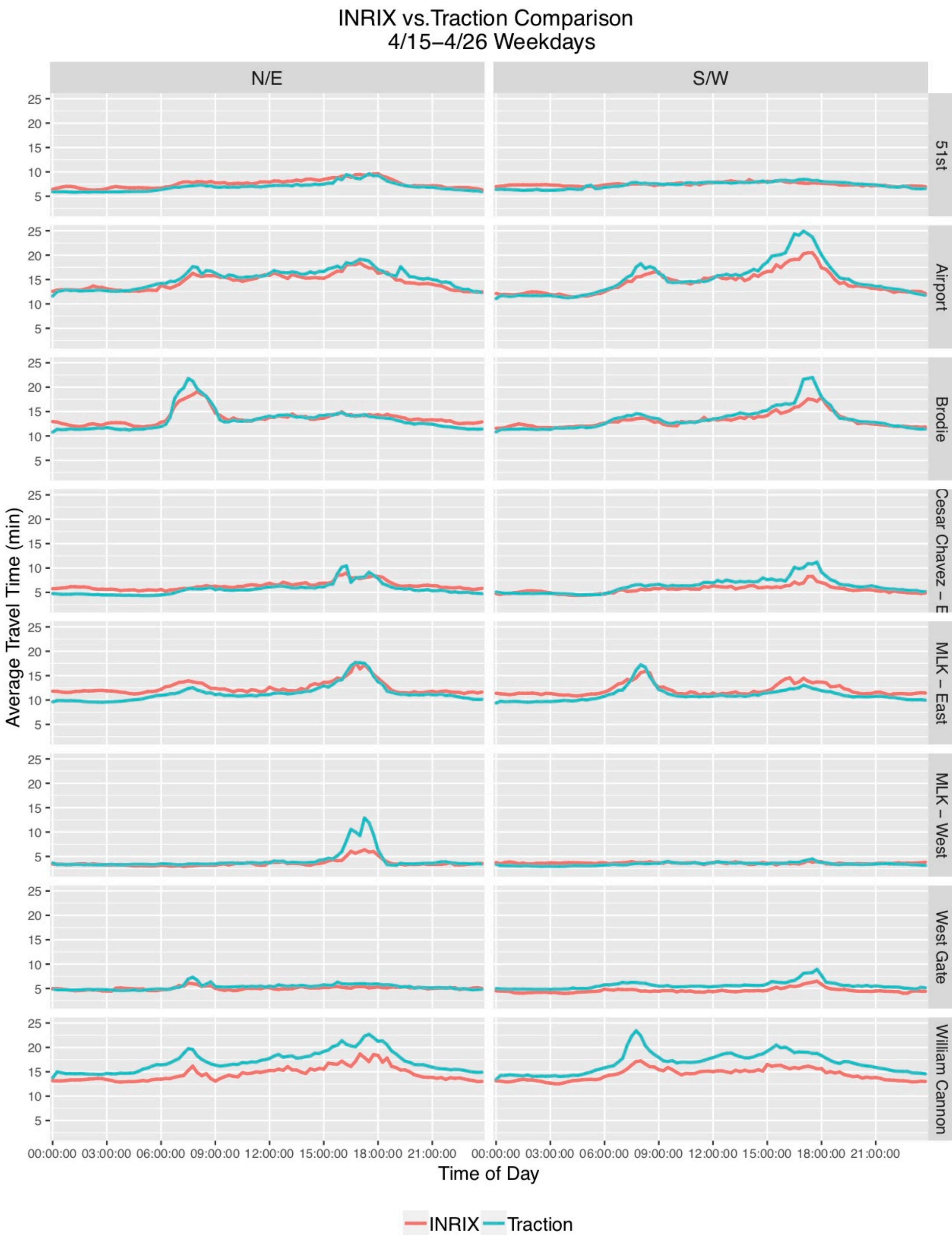

Figure 11: INRIX vs. Traction Comparison for several CoA Corridors

After generating the plots depicted in Figure 11, the inferences made from the data source comparison on Metric Blvd were confirmed: Traction and INRIX both smooth the raw data, producing subdued peak travel times which are more prominently observed with INRIX data. While "true travel time" is impossible to know, this travel time data source analysis helped provide a more informed understanding of the tendencies of each data source in the travel time narrative that each conveys.

The travel time differences observed on Metric Blvd. due to retiming were also computed using the three data sources. These values are shown in Table 1 below. After conducting analysis of variance tests, it was concluded that the changes observed in travel time for the manual runs and INRIX data showed no statistically significant changes, while the Traction data showed a statistically significant increase in travel time by 2.35%. Future work could replicate this analysis on other corridors once they are retimed to obtain a clear sense of whether to conclude that travel time along the corridor changed in cases like this.

Table 1: Corridor Travel Time Change for Metric Blvd. using 3 Data Sources

METRIC		**Runs**		**INRIX**		**Traction**	
TOD	Direction	Before (min)	After (min)	Before (min)	After (min)	Before (min)	After (min)
AM	NB	9.7	9.7	11.3	11.3	11.0	11.3
	SB	13.8	10.6	13.1	12.8	12.7	12.2
OP	NB	9.1	9.7	10.8	11.1	10.6	10.9
	SB	7.6	9.1	11.1	11.4	10.2	10.5
PM	NB	17.4	16.4	13.8	14.2	15.2	16.1
	SB	8.6	9.5	12.2	11.2	10.8	11.1
	TOTAL	66.1	64.9	72.2	72.0	70.5	72.1
		-1.87%		**-0.29%**		**2.35%**	

5.2 EXITING THROUHGPUT VOLUME

W Parmer Ln. has not yet been retimed but due to the presence of three GRIDSMART cameras along its corridor, a throughput metric was developed using data along W Parmer Ln. segments. As Figure 9 illustrates, three GRIDSMART cameras exist along the intersections of W W Parmer Ln. and Lamar Blvd., W Parmer Ln. and Lamplight Village Ave., and W Parmer Ln and Market Ln. The average hourly exiting volume plots of these three intersections are shown in

Figure 12. As visible in the EB direction of W Parmer Ln. and Lamar Blvd., there are unusually low volumes traveling eastbound from W Parmer Ln. at Lamar Blvd. This could be due to a camera malfunction during the time which data was collected since the resulting exiting throughput volumes generated for all other directions at all other intersections are relatively close to TxDOT AADT counts. This was confirmed by calculating the total exiting throughput volumes at each intersection, which are depicted in Figure 13.

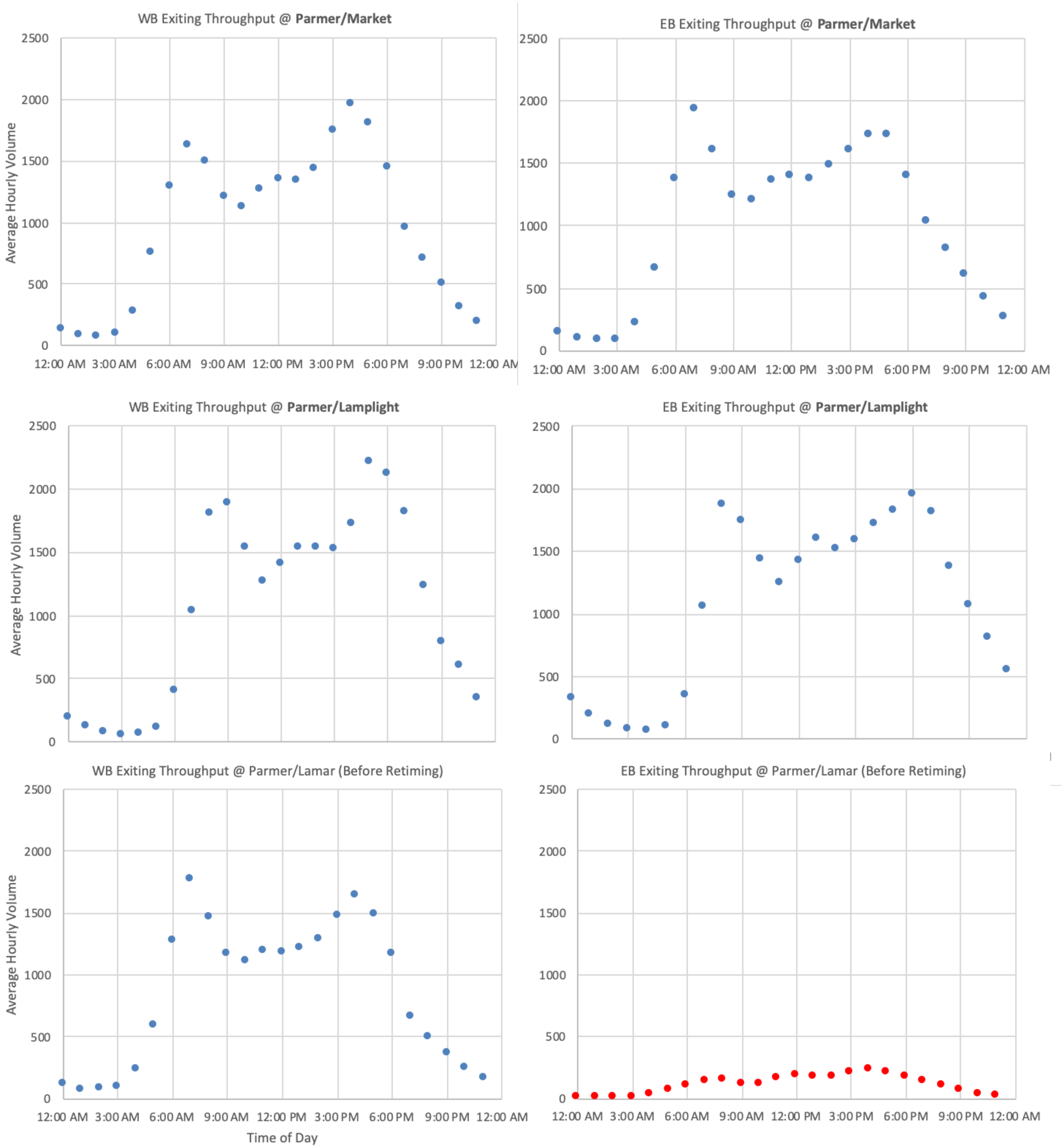

Figure 12: Average Hourly Exiting Throughput for Intersections along Parmer Ln.

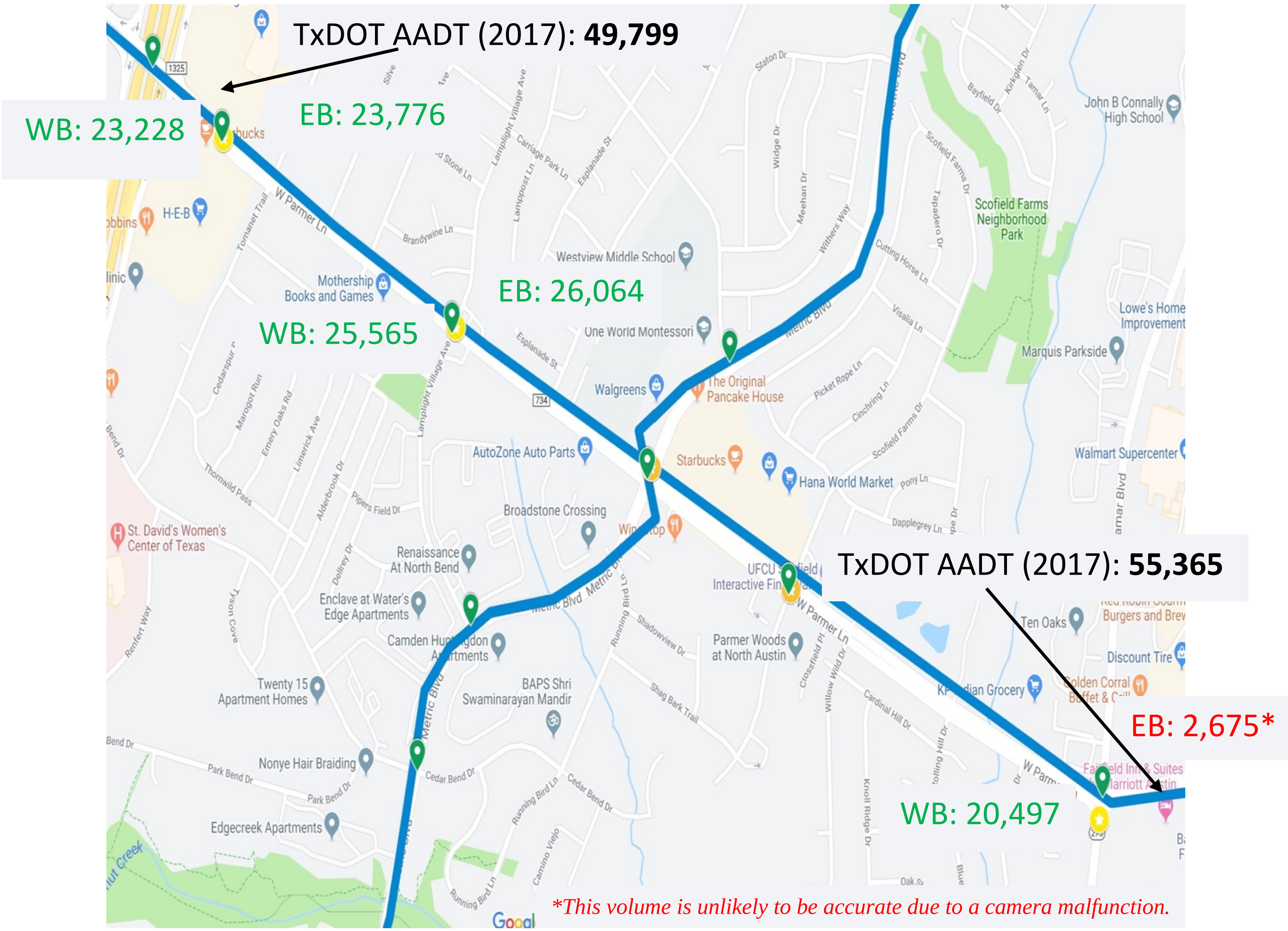

Figure 13: Map of Exiting Throughput Volumes at GRIDSMART enabled intersections on W Parmer Ln. (Google Maps)

5.3 SIDE STREET SPLIT FAILURE CHANGE

When investigating side street split failures, Kimley-Horn's online dashboard and aggregate report function were used to generate visualizations of average split failures (in 15-minute intervals) for all intersections along a corridor. This provided a helpful visual means of determining which specific intersections along a corridor experienced improvement or worsening effects with regards to split failures. Figure 14 compares the changes in split failure occurrences between intersections along Metric Blvd. during the before and after retiming periods. The split failures are also split up by direction to separate split failures occurring on the main (NB/SB) and side streets (EB/WB). One drawback of using the online dashboard to generate visual plots is that there is no flexibility provided to fix the maximum value on the y-axis to ensure easy comparison between plots. Another drawback is as mentioned earlier, there is no ability to select a discontinuous two-week period such as the after retiming period for Metric Blvd. Due to these limitations, it must be noted that the after period plots in Figure 14 are averages of only one week of data rather than two. Figure 14 shows a decrease in the maximum average number of split failures occurring after retiming occurred. It is also interesting to note that for both the main and side streets, there were fewer intersections along the corridor experiencing split failures overall, but more split failures occurring at a few select intersections such as Metric Blvd./Cedar Bend Dr. and Metric Blvd./Parmer Ln.

To evaluate the effect of retiming on side street split failures, the percent change in split failure values for all time of day periods before and after retiming was calculated as shown in Table 2 and Table 3.

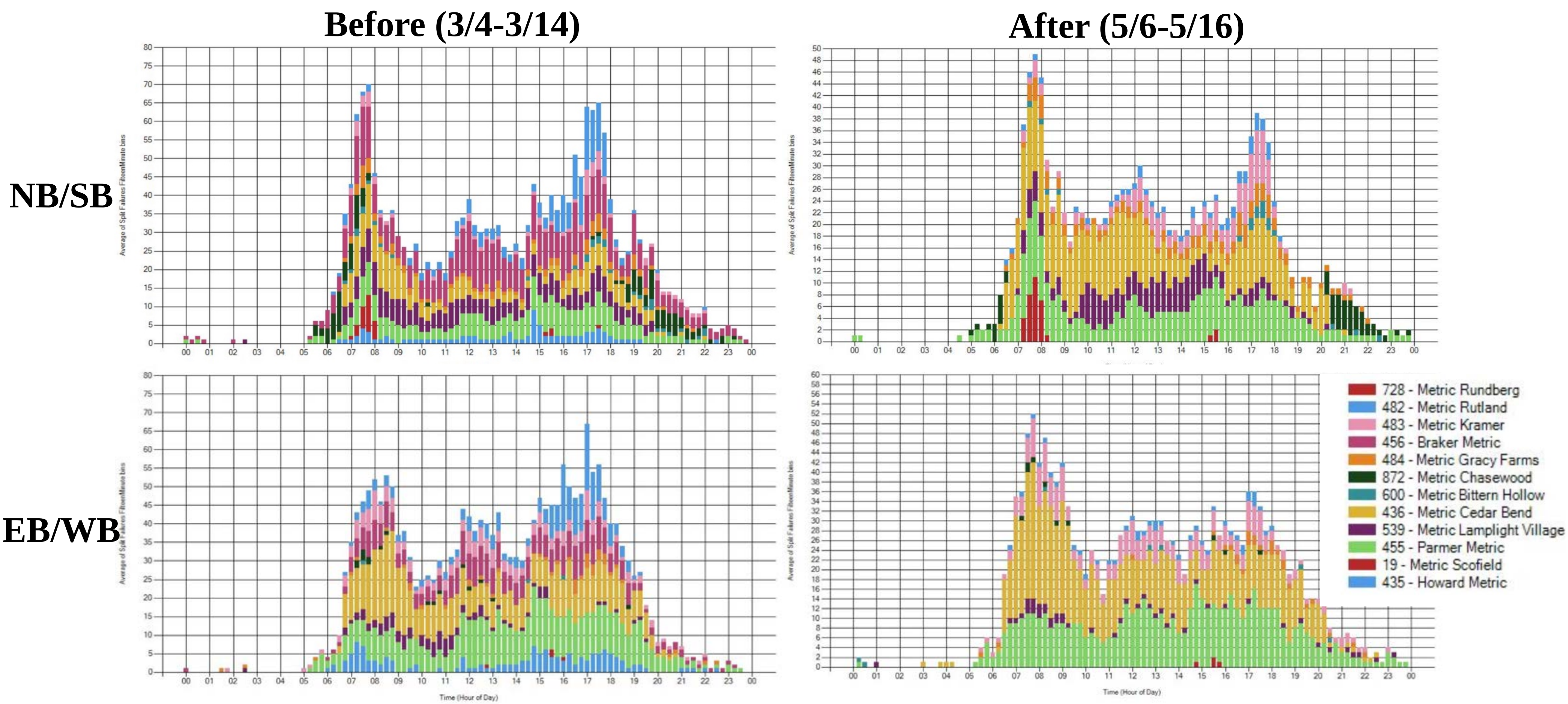

Figure 14: Average # of Split Failures along Metric Blvd. (UDOT)

Table 2: Percent Change in Metric (Side Street) Split Failures

METRIC SIDE STREETS	*Before **Avg # SF/day**	After **Avg # SF/day**	**% Change**
AM	483	1,334	**64%**
OP	260	803	**68%**
PM	422	1,056	**60%**

Table 3: Percent Change in Metric (Major Street) Split Failures

METRIC MAJOR STREET	*Before **Avg # SF/day**	After **Avg # SF/day**	**% Change**
AM	607	607	**0%**
OP	194	358	**46%**
PM	529	552	**4%**

Due to issues mentioned previously with gaps in high-resolution data availability during a server upgrade, split failure data for a few intersections along Metric Blvd. was unavailable and is thus missing from Figure 14, Table 2, and Table 3. Keeping that in mind, the percent changes in split failures were most likely actually lower than the values listed in Table 2, and Table 3. From these tables, it was determined that retiming had a greater adverse impact on Metric Blvd's side streets than on Metric Blvd. itself, confirming initial expectations. In the future, if volume data is also available on corridors with high-resolution data, further work could explore weighting the percent changes in split failures with corridor volumes to better quantify the magnitude of these observed split failure changes.

5.4 PEDESTRIAN DELAY CHANGE

Despite the lack of accessibility to raw high-resolution data, one raw high-resolution data file was available for the intersection of Metric Blvd. and Kramer Ln. on April 28^{th,} 2019. Using this data, a Delay Time vs Time of Day plot was created as show below in Figure 15. For this particular intersection at this particular day, the 85th percentile pedestrian delay was calculated to be 48.14 seconds. In the future, when access to sufficient high-resolution data to conduct a full before/after retiming analysis is possible, an average 85th percentile delay value among all intersections can be computed for the two-week before period on Metric Blvd. and compared to the same for the after period to compute a percent difference in the 85th percentile delay times. Future work could also include extracting pedestrian push information (number of pedestrians waiting at an intersection) from high-resolution data to weight the corresponding delays.

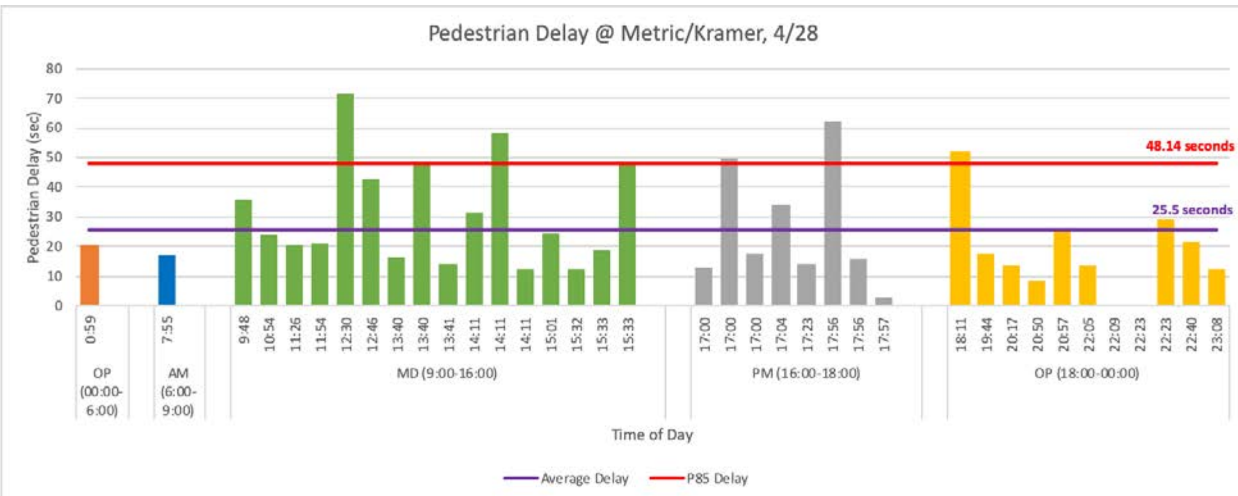

Figure 15: Pedestrian Delay at Metric Blvd./Kramer Ln. on April 28th

5.5 TRANSIT VEHICLE SPEED CHANGE

Using AVL data streamed every two-minutes, a preliminary plot of average hourly corridor speeds by transit vehicles across both the before and after retiming periods for Metric Blvd. was created as shown in Figure 16. Transit speeds were analyzed as opposed to transit travel times as a way of normalizing the effects of varying corridor lengths when comparing metrics across corridors. A 35% corridor coverage threshold was set for determining which data points would be included in this plot. Without knowing with certainty which part(s) of the Metric corridor are covered by the long-spanning AVL data points as well as not knowing dwell times at transit stops along the corridor, it is difficult to conclude whether transit speeds along Metric improved or worsened from Figure 16. When CapMetro data becomes available, future work could greatly improve the accuracy and meaningfulness of this metric. However, it is interesting to see that there is significant variability in the early morning hours for the after-retiming period.

This suggests that there are too few buses traveling long enough within 35% of the corridor to generate a representative speed value.

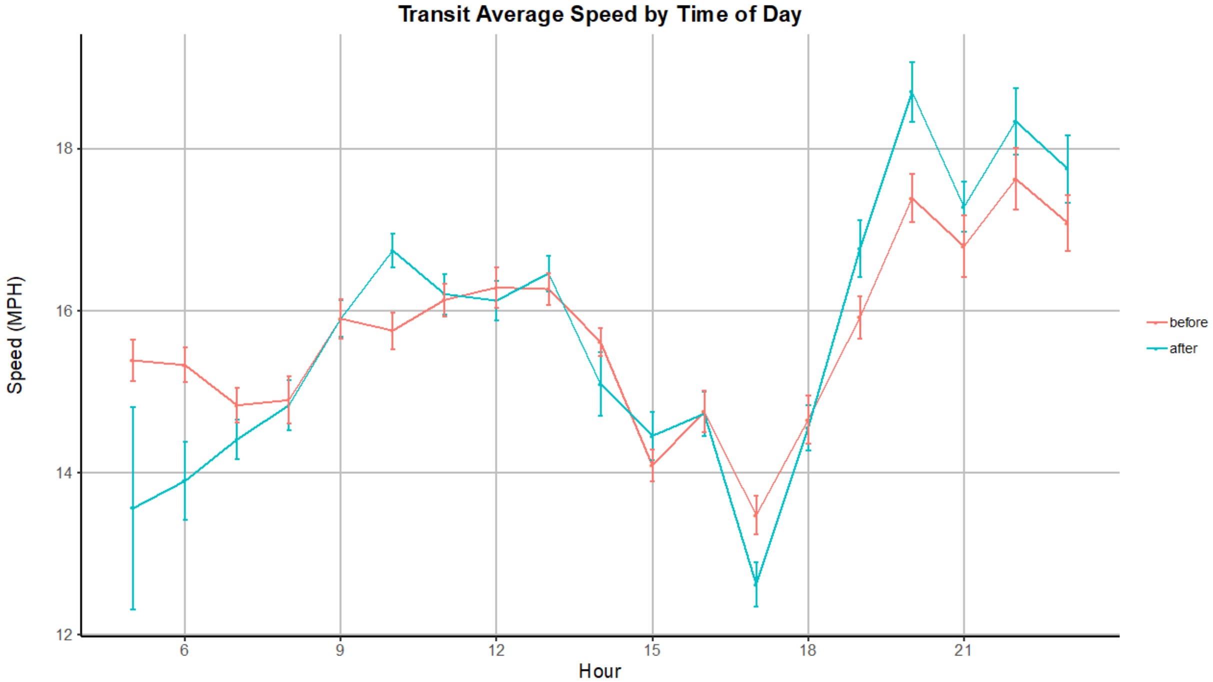

Figure 16: Transit Average Corridor Speed by Time of Day

5.6 RELIABILITY INDEX CHANGE (PEAK BUFFER INDEX ACROSS DAYS)

The average across day buffer indices for before/after retiming scenarios on Metric Blvd. and Westgate Blvd. were calculated since both corridors were retimed at the time of analysis and INRIX data was available for both. Table 4 summarizes the average buffer index observed during peak times of travel in each direction along Metric Blvd. and Westgate Blvd. where the AM Peak occurs going SB on Metric Blvd., NB on Westgate Blvd., and vice versa for the PM peak. The values summarized in Table 4 suggest that Westgate Blvd. as a whole saw an improvement in reliability as a result of retiming along the corridor while Metric Blvd. experienced an improvement in reliability in the SB direction and a reduction in reliability in the NB direction. Future research into reliability indices could investigate the statistical significance of these changes to determine if the suggested trends are due to retiming effects or chance alone.

Table 4: Peak Buffer Index Across Days for Metric and Westgate Corridors

Peak Buffer Index Across Days					
METRIC	Before	After	WESTGATE	Before	After
NB (5-7 PM)	0.10	0.12	NB (7-9 AM)	0.15	0.12
SB (7-9 AM)	0.14	0.10	SB (5-7 PM)	0.14	0.10

5.7 SUMMARY OF 2019 RETIMING EVALUATION RESULTS

The six previously discussed metrics were applied to an evaluation of a few Austin corridors that were scheduled for retiming during the development process to assess retiming efforts and to further refine the developed metrics. In terms of travel time evaluation, Metric Blvd. was found to have statistically insignificant changes in travel time according to percent travel time changes calculated using both floating car run data and INRIX data. Traction data, on the other hand, illustrated a statistically significant decrease in travel time along the corridor of 2.35%. A comparison between the three travel time data sources also revealed that both Traction and INRIX data provide peak travel times that appear less pronounced than those observed with floating car runs. Between the two probe vehicle data sources, INRIX also appeared to have the largest data smoothing effect.

A full before-and-after evaluation of throughput was not possible due to the lack of coinciding GRIDSMART data with corridors scheduled for retiming. However, a preliminary evaluation of throughput volume on W Parmer Ln. showed exiting Eastbound and Westbound volumes between 23,000 to 26,000 vehicles along several intersections during the before retiming period and were validated by 2017 TxDOT AADT counts.

An evaluation of split failures along Metric Blvd. revealed an overall worsening effect due to retiming with Metric Blvd's side streets being impacted much more negatively than Metric Blvd. itself. Similar to the throughput metric, a full before-and-after evaluation of pedestrian delay change was not possible due to lack of data. However, a proof of concept application of the metric was conducted for a single day data sample at the intersection of Metric Blvd. and Kramer Ln.

Low-resolution AVL data was used to generate a preliminary before-and-after transit average speed change plot for Metric Blvd. but without higher resolution data, it is difficult to conclude at this time whether the retiming improved or worsened transit vehicle speeds along the corridor.

Finally, a reliability index evaluation of retiming along Metric Blvd. and Westgate Blvd. suggested that the Westgate Blvd. corridor saw an overall improvement in reliability (i.e. less variability in travel time across days during the study periods) while Metric Blvd. observed improved reliability conditions in one direction and worsened conditions in another direction.

Overall, the application of the six metrics to several Austin corridors where possible (given data availability) not only provided insight into the quality of several recent retiming efforts but also assessed the usability and effectiveness of the developed metrics.

Chapter 6: Conclusions and Recommendations for Part 1

This research work explored data sources available to the City of Austin to determine a set of meaningful performance metrics to evaluate the quality of retiming efforts across corridors. In addition, an updated corridor ranking list was created to recommend top priority corridors for retiming to CoA staff. The developed metrics are intended to provide city officials and the Austin public a more holistic understanding of the effects of CoA staff's retiming efforts by incorporating multi-modal travel and considering side streets along a corridor. This report detailed the existing signal retiming evaluation process used by the CoA, reviewed relevant literature, described the development of metrics for retiming evaluation, and analyzed the results of applying metrics to corridors retimed in 2019.

The developed metrics include percent end-to-end corridor travel time reduction, exiting throughput volume, side street split failure change, pedestrian delay change, transit vehicle speed change, and reliability (across days) index change. An analysis of similar data sources was also conducted for travel time information to observe differences in the data reported for the same location and time among INRIX, Traction, and floating car travel time runs. Moving forward, the CoA will most likely continue using INRIX data given its comprehensive coverage. Thus, it will be useful to keep in mind that INRIX has an averaging effect when data is used for future purposes.

There are many ways to extend this work in the future with data availability and accessibility changes. A number of performance metrics were incomplete in their development due to issues associated with data availability and/or access including raw high-resolution data, AVL/APC data, and GRIDSMART data. Thus, future work could involve finishing development of metrics such as transit vehicle speed change and also improving upon metrics such as split failures and pedestrian delay by weighting metric values with volume data to evaluate the effects of retiming relative to the volume of vehicles impacted by these changes. The corridor travel time metric could be improved to also include the possibility of analyzing travel time changes on portions of corridors rather than in their entirety since most individuals do not travel an entire corridor from end to end. Furthermore, each of the six metrics could be weighted and combined to provide a single metric value that gives a higher-level assessment of retiming efforts.

PART 2: CORRIDOR PRIORITIZATION FOR 2020 RETIMING LIST

Previous work conducted for the CoA included developing a data-driven methodology for prioritizing which Austin corridors to retime, which would inform signal engineers which signals to retime each year. While analyzing the evaluation of ongoing signal retiming efforts, additional work was also completed to build upon this previous signal prioritization research to utilize the INRIX API (Application Programming Interface) and expedite the data downloading process required. In addition, the previously developed signal prioritization methodology was used to generate an updated ranking list of priority corridors for retiming in 2020.

Chapter 7: Applying Prioritization Methodology for 2020 Retiming List

One key difference in methodology between the development of this ranking list and the list developed previously was the comparison dates used to calculate speed changes along CoA corridors. In the previously developed signal prioritization methodology, the two comparison periods were September 2016 and September 2017. For this project, the CoA was interested in comparing the closest "usable" month after retiming last occurred on a corridor to its equivalent month in 2019 to determine the magnitude of deterioration along a corridor since the last time that it was retimed. This meant that different CoA corridors were compared using different time periods.

Since the last ranking list was compiled, INRIX Analytics underwent several map updates where segment IDs were changed. As a result, every previously defined corridor study saved in INRIX had to be manually checked to ensure that the map update changes did not drastically change the boundaries of a corridor. The full 2020 corridor ranking list developed for the CoA is shown below in Appendix B. CoA signal engineers combined the results of this ranking with their engineering intuition on corridors in need of retiming to ultimately finalize a corridor retiming list for 2020 that was need-based as opposed to schedule based.

A preliminary Python script was also written that could make an API call for INRIX data to expedite the process of data downloading for future iterations of this work. This script allows the user to circumvent the process of downloading individual files for each corridor by specifying a list of segment IDs for multiple corridors.

In the future, depending on the consistency of data availability across Austin, future work might attempt to apply retiming metrics to prioritization efforts as well to form a feedback loop where the same set of metrics that inform which corridors are retimed are also used to assess the retiming efforts. While it is easier to conduct evaluations of retiming with non-uniform data availability across the City since certain metrics can simply be left out of the evaluation for a certain corridor, it will be even more imperative to improve the uniformity of data availability across Austin corridors for any continued work on corridor prioritization so that every corridor is ranked based on equivalent metrics.

PART 3: SEASONAL VARIATION OF CORRIDOR SPEEDS

As a supplement to the signal retiming evaluation work, the final phase of this research involved investigating the seasonal variation of corridor speeds across the City of Austin. In Austin, CoA signal engineers are often constrained in their retiming schedule by frequent special events occurring around the city that affect traffic patterns in a way that diverges from the typical pattern. The University of Texas at Austin semester school schedule as well as large events such as Austin City Limits Festival, South by Southwest, and Formula 1 United States Grand Prix affect travel demand across different parts of the city at different times of the year. Thus, obtaining equivalent data for before and after signal retiming comparison studies where traffic patterns are not abnormal for either period often means signal engineers have small windows of time throughout a year where they are able to conduct signal retiming.

In an effort to improve the flexibility of CoA signal engineers' retiming schedules, an analysis on Austin corridor speed variation was conducted to provide indices of time-wise variation that could potentially be used to estimate corridor speeds at a specific time of the year if that data is unavailable due to the aforementioned constraints.

Chapter 8: Indices of Time-Wise Variation for Corridor Speeds

Before conducting seasonal variation analyses on multiple Austin corridors, the sample corridor of South Lamar Blvd. was selected as a case study. South Lamar Blvd. is not only a key Austin arterial, but it also possesses heavy directionality during peak times and was thought to be an excellent first corridor with which to investigate seasonal variation. Figure 17 shows the location of the South Lamar Blvd. corridor, where it begins on the north end at 24th St. and continues to Ben White Blvd. on the south.

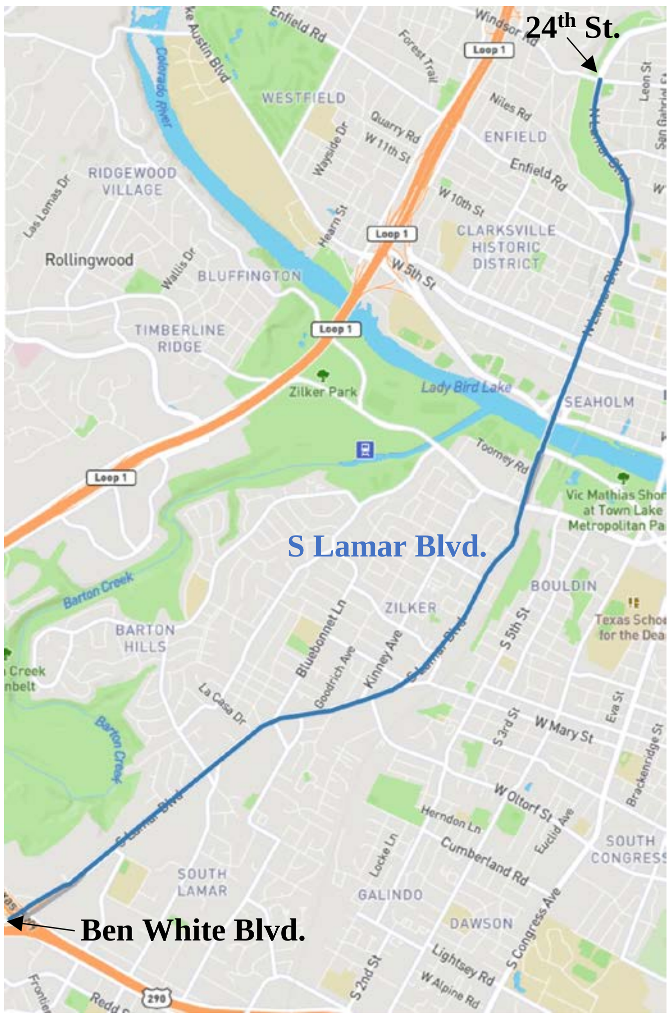

Figure 17: Map of South Lamar Blvd. Corridor in Austin (INRIX)

8.1: SEASONAL VARIATION CASE STUDY - DATA SAMPLE

Three years' worth of travel time data from 2016 to 2018 along South Lamar Blvd. was obtained from INRIX.[1] This travel time data was selected to include only weekdays throughout the year and only AM and PM peak time frames which are estimated to be approximately 7:00 AM to 9:00 AM and 4:00 PM to 6:00 PM, respectively. Weekend travel is often highly irregular and inconsistent and for those reasons was left out of this study. Peak travel time data was chosen to be used because it was thought to produce more distinct indices of time-wise variation than 24-hours' worth of data that included many hours of data with little to no congestion. At a data granularity of 15-minutes, this entire data sample comprised of 513,328 records in total.

8.2: SEASONAL VARIATION CASE STUDY – METHODOLOGY

After obtaining the travel time data along every segment for South Lamar Blvd., a series of calculations were conducted with the data to result in corridor speed values. Since INRIX provides segment-based travel time data, the travel times on individual segments of the corridor were first summed together to result in corridor travel times at every timestamp. These corridor travel times were then converted to corridor speeds by dividing the distance of the corridor by each corridor travel time record.

Next, monthly average corridor speeds were computed for the corridor by averaging corridor speed values across both AM and PM peaks in both north and south directions for all weekdays per month. A plot illustrating these monthly average corridor speed values and their associated standard deviation values is shown in Figure 18. Figure 18 shows how the process of averaging corridor speeds across peak times and directions for each month resulted in very similar final speeds for each month. Although not ideal for capturing the directionality that is inherent to South Lamar Blvd., the monthly average does serve the purpose of capturing the performance of a corridor from month to month. It also aligns with the CoA's desire to ultimately create either a set of indices for all corridors in Austin or a single set of indices that

[1] Three years' worth of data was required to supply enough data for the computational process of conducting a centered 12-month moving average method of analysis, which loses a full year's worth of data in its computational process.

represent the city-wide seasonal variation, which requires a bird's eye view perspective of corridor performance rather than a directional and/or peak time segmented-based approach.

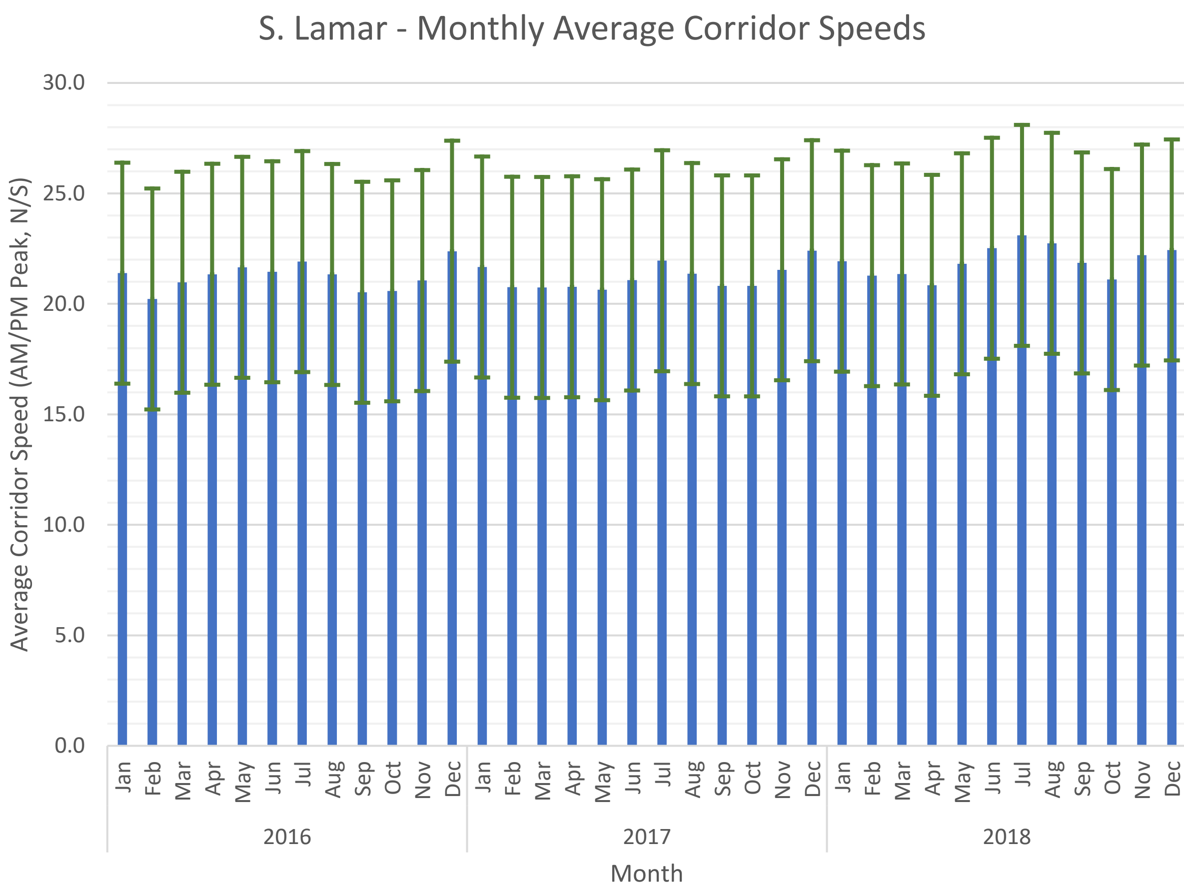

Figure 18: Plot of Monthly Average Corridor Speeds on South Lamar Blvd.

Using these monthly average corridor speeds, a moving average method of analysis was conducted, ultimately producing ratios of each monthly average speed to the 12-month moving average centered at those months. These ratios, or monthly indices, are shown in Table 5.

8.2: SEASONAL VARIATION CASE STUDY – RESULTS

The interpretation of the monthly index for January would be that on average for the years 2016 to 2018, South Lamar Blvd. corridor speeds in January tended to be 2.3% higher than the average corridor speed for the year (centered on January).

Table 5: Seasonal Indices of Time-Wise Variation for South Lamar

Month	Seasonal Indices
January	102.3
February	98.3
March	98.2
April	96.9
May	98.7
June	101.2
July	103.5
August	100.6
September	97.2
October	97.4
November	100.2
December	105.3

The index values in Table 5 show slight variations in corridor speeds across the year but nothing drastically different. Higher corridor speeds in months such as June, July, December, and January could be due to less University of Texas at Austin related traffic during the summer and winter breaks. Future work will continue to apply this methodology to other corridors across Austin (a mixture of north-south and east-west corridors scattered around the city) to ascertain if and how different corridors around the city vary similarly in speeds throughout the year. By maintaining a corridor-level analysis approach, there is opportunity in the future to consider aggregating these indices to a city-wide set of indices if the results indicate similar variations. Future work will also include investigation into creating weekly indices of variation as opposed to monthly indices in order to consider the effect of short duration events such as The University of Texas at Austin's spring break week in March that might affect travel patterns during only a portion of a month.

By investigating the seasonal variations of corridor speeds, there is great potential for these calculated indices to supplement the previously discussed evaluation work, particularly in the data collection and retiming schedule aspects. While CoA engineers may have their own intuitional understanding of the seasonal variation throughout the city, these monthly indices help to quantitatively define the effect of season on traffic patterns and can help engineers identify if the changes observed on corridors due to their retiming efforts were a result of the retiming itself or if seasonal variation played a role as well.

APPENDICES

Appendix A – Performance Metric Fact Sheets for Retimed Corridors

METRIC BLVD:	
Retiming Evaluation Performance Metrics **Date of Retiming: 4/2/19** **Before Retiming Period: 3/4/19 – 3/14/19 (M, T, W, Th)** **After Retiming Period: 5/6/19 – 5/9/19, 5/20/19 – 5/23/19**	
% Travel Time Change **Runs:** **-1.87%** **INRIX:** **-0.29%** **Traction:** **+2.35%**	% Throughput Volume Change N/A (No GRIDSMART cameras)
% Side Street Split Failure Change **AM:** **+64%** **OP:** **+68%** **PM:** **+60%**	85th Percentile Pedestrian Delay N/A (Waiting on access to raw high-resolution data)
% Travel Time Buffer Change **NB:** **+20%** **SB:** **-29%**	Transit Speed Change N/A (Waiting on higher-resolution AVL data/APC data)

WEST GATE BLVD:	
Retiming Evaluation Performance Metrics **Date of Retiming: 7/9/19 – 7/12/19** **Before Retiming: 6/17 – 6/28 (M, T, W, Th)** **After Retiming: 7/15 – 7/26/19 (M, T, W, Th)**	
% Travel Time Change **Runs: Not conducted** **INRIX: N/A** **Traction: N/A** **(Not analyzed due to overall lack of data)**	% Throughput Volume Change N/A (No GRIDSMART cameras)
% Side Street Split Failure Change **N/A** **(No high-resolution data available)**	85th Percentile Pedestrian Delay N/A (No high-resolution data available)
% Travel Time Buffer Change **NB:** -20% **SB:** -29%	Transit Speed Change N/A (Waiting on higher-resolution AVL data/APC data)

Appendix B – Full Corridor Ranking

The following table includes the ranking and calculated ranking metrics for all seventy-three corridors examined for determination of corridors for 2020 Retiming.

Table 6: 2020 Full Corridor Ranking Metrics List

		Percent of Corridor Experiencing Speed Decrease			Percent of corridor Experiencing Speed Decrease > 3 mph			Maximum Speed Decrease (mph)					
Rank	Corridor	AM	Midday	PM	AM	Midday	PM	AM	Midday	PM	Total Length (mi)	Number of Signals	% Travel Time Change
1	IH 35 SRVC RDS	100	100	100	76.8	82.7	100	-18.4	-19.4	-16.5	2.2	16	22.1
2	Ben White - East	100	100	100	80.2	55.9	80	-19.2	-17.4	-14.1	3.8	14	19.5
3	RM 620	100	100	100	99	98.9	87.9	-8.6	-9.3	-11.2	6.4	23	18.5
4	RM 2222 - Central	100	100	100	97.1	76.6	57.4	-13.8	-7.9	-11.4	2.9	7	9.1
5	US 183 - South	100	100	63.5	63.5	100	50.3	-24.3	-25.3	-17.4	2.1	15	6.7
6	Southwest Parkway	100	100	100	94.4	94.4	94.4	-9.4	-7.2	-6.8	3.1	18	10.4
7	Burleson	87.8	99.6	80.2	59	86.4	68.5	-14.6	-14.6	-11.4	3.6	11	10.3
8	Wells Branch	100	100	100	62.5	62.5	49.3	-8.3	-7.8	-12.7	4.4	13	11
9	Anderson Mill - West	100	100	100	100	60.1	100	-8.9	-5.8	-6.5	1.6	4	15.5
10	US 183 - Central	99	84.7	83.8	83.3	37.8	39	-10.2	-9.2	-11.1	3.0	10	4.8
11	Pleasant Valley	100	100	100	55.7	74.2	60.1	-5.8	-5.1	-9.2	2.5	11	13.6
12	US 290 - East	96.8	71.5	96.8	50.7	47.3	31.3	-14	-11.1	-12.9	5.6	19	5.8
13	RM 2222 - West	100	100	100	66.7	100	66.7	-4.6	-4.6	-6.1	1.7	4	2.7
14	Cameron - South	100	98.7	98.7	39.4	45.3	47.8	-9	-6.8	-4.2	2.1	14	8.7
15	Cameron - North	100	100	84.9	65	57.6	15.7	-8.1	-8.2	-3.8	3.6	11	12.2
16	Howard	100	65.5	65.5	33.4	22.3	33.4	-15.8	-12.8	-15.6	3.7	8	9
17	Slaughter	92.4	73.2	82.3	46.9	47.2	16.8	-8.6	-10.4	-7.7	6.6	31	5.6
18	Loop 360 - North	81.3	71.3	98	21.2	25.6	59.3	-9.1	-8.7	-7.7	8.2	14	0
19	Lakeline	96.9	96.9	96.9	33.3	63.9	56.2	-3.4	-5.6	-3.3	1.0	6	9.8
20	Montopolis	96.6	82.2	65.6	43.9	45.2	24.5	-7.3	-6.4	-9.1	2.9	9	4.8
21	Anderson Mill - East	69.4	98.1	53.5	28.4	28	30	-10.2	-8.3	-10.1	3.2	8	4.6
21	Lamar - North	87.8	87.8	86.6	36.9	38.3	25.5	-6.1	-7.5	-5.8	4.2	15	3.9
23	Yager	100	100	100	90.3	0	90.3	-3.5	-2.6	-4.6	0.7	3	11.4
24	St Johns	100	100	100	2.1	50.7	47.3	-5.1	-3.1	-4.3	1.8	8	3
25	US 183 - North	96.8	88.4	80.1	30.1	51.3	14.8	-6.7	-5	-6.4	2.3	15	5.6
26	12th - East	93.7	100	93.7	0	50.7	93.7	-2.8	-3.5	-4.5	1.4	7	6.2
27	Airport	98.7	76.3	56.1	14.2	24.4	17.8	-9.3	-9.6	-6.8	6.3	27	2.5

Table 6, cont.

Rank	Corridor	Percent of Corridor Experiencing Speed Decrease			Percent of corridor Experiencing Speed Decrease > 3 mph			Maximum Speed Decrease (mph)			Total Length (mi)	Number of Signals	% Travel Time Change
		AM	Midday	PM	AM	Midday	PM	AM	Midday	PM			
28	Great Hills	56.7	36.9	56.7	31.3	35.6	35.6	-9.3	-10.1	-7.8	1.1	6	23.7
29	Braker	78.1	83.4	57.5	14.7	26.9	10.8	-8.3	-11.3	-7.3	5.6	19	3.5
29	Parmer - East	98.9	98.9	98.7	35.7	34.7	0.5	-3.7	-3.2	-4.3	1.8	4	2.5
31	US 290 - West	97.1	83.5	100	27.5	19.6	0.3	-7	-5.1	-4.4	2.4	9	6.2
32	McNeil/Spicewood Spgs	85.4	62.3	77.8	45.1	24.6	35.1	-5.1	-6.9	-4.3	5	19	1.8
33	Stassney - West	43.2	59.7	65.2	25.6	25.6	47.6	-6.3	-7.6	-8.2	3.0	8	-3.1
34	Congress - South	96	79.5	91.9	17.9	1.2	16.8	-7.2	-4.7	-3.5	3.2	24	2.6
35	Lamar - Central	70.9	65.5	71.3	12.7	24.7	16.1	-7.2	-5.9	-7.4	4.4	15	2.3
36	Manor	56.8	62.7	75.9	22	12.8	30.8	-6.4	-4.5	-9.3	4.7	15	11
37	7th - East	79.1	75.1	98	16.6	16.6	16.6	-4.3	-4.2	-5.8	2.6	12	38
38	William Cannon	56	74.2	63.4	15.8	14.1	21	-7.4	-7.3	-6.4	7.4	30	3.9
39	Lamar - South	48.6	79	55.1	3.9	26.1	3.2	-8.1	-8.1	-6.6	5	26	0.1
40	RM 2222 - East	33.3	63.4	70.4	32	32	32	-3.9	-3	-7.1	1.7	3	1.2
41	Jollyville	41.8	77.6	78.6	0	36.7	59.2	-1.6	-3.7	-6.7	2.6	5	5.6
42	Trinity	100	100	100	0	0	0	-2.7	-1.9	-2.7	0.4	6	20.6
43	Red River - South	100	100	82.3	0	0	0	-1.9	-2.5	-2.7	0.8	9	2.6
44	Barton Springs	18	89.7	89.1	0	3.7	0	-2.9	-5.7	-2.7	1.3	9	-1.6
45	Stassney - East	100	100	100	0	0	0	-2.2	-1.8	-1.6	1.9	7	1.2
46	Riverside	77	77	70.1	1.5	2.3	0.8	-3.2	-4.9	-3.4	3.8	24	1.7
47	8th	69	90.4	100	0	0	9.3	-1.3	-2.9	-3.5	0.7	10	3.6
48	Woodward	81.7	47.7	76.1	0	4.9	4.9	-2.9	-3.3	-4.3	1.1	9	-4.4
49	San Jacinto	100	100	100	0	0	0	-1.8	-1.3	-1.2	0.5	8	11.3
50	Far West	91.9	91.9	91.9	0	0	0	-2.2	-1.8	-2.4	1.2	5	0.6
50	Guadalupe - South	19.7	100	100	0	9	0	-1.2	-3.7	-2.2	0.8	12	3.1
50	Oltorf	91.2	85.5	67.9	19.5	0	0	-3.4	-2	-2	3.5	14	0
53	12th - West	61.5	86.9	100	0	0	0	-2.5	-1.9	-2.4	0.5	7	1.1
54	45th	54.9	56	4.9	3.6	3.6	3.6	-4.9	-3.1	-4.5	2.1	11	-4.6

Table 6, cont.

		Percent of Corridor Experiencing Speed Decrease			Percent of corridor Experiencing Speed Decrease > 3 mph			Maximum Speed Decrease (mph)					
Rank	**Corridor**	**AM**	**Midday**	**PM**	**AM**	**Midday**	**PM**	**AM**	**Midday**	**PM**	**Total Length (mi)**	**Number of Signals**	**% Travel Time Change**
55	Cesar Chavez - W	88.9	42.7	74.9	1.3	1.3	0	-3.1	-3.1	-2.6	2	15	1
56	38th	78.8	79.6	78.1	0	0	0	-2.2	-1.6	-2.7	2.2	12	-1
57	11th	82.5	75.3	100	0	0	0	-1.5	-2.1	-1.6	0.8	10	4.5
58	Congress - North	69.6	50	79.7	0	9.8	0	-1.9	-3.1	-2.4	0.7	20	-0.6
59	7th - West	100	87.1	50.2	0	0	0	-1.9	-0.9	-1.8	0.8	12	101
60	Manchaca	42.3	51	42.1	0	0.0	22.6	-2.2	-2.2	-4.6	6.5	15	-4.4
61	South 1st - North	69.8	70.2	23.9	0	19.8	0	-2.9	-3.3	-1.4	3	14	0.6
62	5th	65.4	86.7	64.5	0	0	0	-2.1	-2.4	-2.1	1.6	18	3.1
62	South 1st - South	35.4	42.8	42.6	0.3	0	11.6	-3.9	-2.8	-3.8	4.1	8	-0.1
64	Exposition	27.5	78.8	100	0	0	0	-0.3	-2.6	-1.7	2.1	12	-1.7
65	6th	41.5	37.9	29.6	0	3.6	3.6	-2.7	-3.2	-3.6	1.9	20	1.8
65	Lavaca	55.8	100	55.8	0	0	0	-0.9	-1.2	-2.6	0.8	13	1.3
65	Steck	100	8.4	32.6	0	0	8.4	-2.1	-0.6	-3.1	0.9	6	12.1
68	Loyola	1.7	1.7	1.7	1.7	1.7	0	-5.7	-5.1	-1.7	0.8	3	-49.8
69	Guadalupe - North	29.2	29.2	31.2	0	0	29.2	-0.8	-2.6	-4	2.2	17	-7.8
70	Anderson	47.8	49.3	46.1	0	0	0	-1.5	-1.7	-1.8	2.3	10	-4.5
71	Enfield	11.7	10.7	9.4	0	0	0	-2.6	-2	-1	1.5	9	-10.3
72	Dean Keeton	0	0	0	0	0	0	0.6	0.2	-0.1	1	10	-2.1
73	24th	0	0	0	0	0	0	0.7	1.3	1	0.7	6	-12.4

Glossary

AADT	-	Annual Average Daily Traffic
API	-	Application Programming Interface
ATSPMs	-	Automated Traffic Signal Performance Measures
AVL	-	Automatic Vehicle Location
APC	-	Automatic Passenger Count
CapMetro	-	Capital Metro Transportation Authority
CoA	-	City of Austin
PCD	-	Purdue Coordination Diagram
PSQL	-	PostgreSQL (Database Management System)
TxDOT	-	Texas Department of Transportation

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